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Perspectives

International nanotechnology development in 2003: Country, institution, and technology field analysis based on USPTO patent database

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Abstract

Nanoscale science and engineering (NSE) have seen rapid growth and expansion in new areas in recent years. This paper provides an international patent analysis using the U.S. Patent and Trademark Office (USPTO) data searched by keywords of the entire text: title, abstract, claims, and specifications. A fraction of these patents fully satisfy the National Nanotechnology Initiative definition of nanotechnology (which requires exploiting specific phenomena and direct manipulation at the nanoscale), while others only make use of NSE tools and methods of investigation. In previous work we proposed an integrated patent analysis and visualization framework of patent content mapping for the NSE field and of knowledge flow pattern identification until 2002. In this paper, the results are updated for 2003, and the new trends are presented.

The number of USPTO patents originated from all countries that include nanotechnology-related keywords in 2003 is about 8600, an increase of about 50% over the last 3 years, which is significantly larger than the increase of about 4% for patents in all technology fields (USPTO, 2004). The top five countries are U.S. (5228 patents in 2004), Japan (926), Germany (684), Canada (244) and France (183). Fastest growing are the Republic of Korea (84 patents in 2003) and Netherlands (81). For the first time in 2003, four electronic companies have reached the top five institutions: IBM (198 patents), Micron Technologies (129), Advanced Micro Devices (128), Intel (90) and University of California (89). However, overall, the single technology field "Chemistry: molecular biology and microbiology" and chemical industry remain in the lead. The citation networks show an increase of international interactions, and a relative change of the role of various countries, institutions and technological fields in time.

Introduction

Recent rapid development of Nanoscale Science and Engineering (NSE) promises fundamental changes to a wide range of research fields and industries, revolutionizing applications such as detecting and treating disease, monitoring and protecting the environment, producing and storing energy, and building complex structures for electronic circuits or airplanes. Nanotechnology is expected to have broad implications on various sectors of the economy, leading to new products, new businesses, new jobs, and even new industries. After 2000, nanotechnology has been recognized as a national priority in all industrialized countries and many countries in development. The United

States announced the *National Nanotechnology Initiative* (NNI) in 2000 based on a long-term vision (Roco et al., 2000). In December 2003, President Bush signed into law the *21st Century Nanotechnology Research and Development Act*, which authorizes funding for nanotechnology research and development over 4 years, starting in fiscal year 2005. More than 40 countries have adopted national projects or programs partially stimulated by NNI.

An important characteristic of NSE research and development is its interdisciplinary nature. Both long-term basic research and short-term development related to NSE are being actively explored across many scientific fields and industrial applications, such as material science, molecular biology, optics, and semiconductor fields. The speed and scope of NSE development make it critical for researchers to be aware of progress in the field across different laboratories, companies, industries, and countries. This development makes such awareness of the large picture of the development of the field challenging, and requires use of intelligent searching of databases.

Extending the patent analysis literature (Garfield, 1955; Karki, 1997; Oppenheim, 2000), we previously proposed an integrated framework for automatically assessing and mapping the development of the NSE field through analyzing patent documents. We used patent data from the United States Patent and Trademark Office (USPTO) for the years 1976 to 2002 and provided longitudinal analysis of active countries, institutions, and technology fields in NSE (Huang et al., 2003). Three types of analysis of these analytical units were reported: 'basic analysis', citation network analysis, and content map analysis. The basic analysis and citation network analysis provide valuable information in assessing the performances of different countries, institutions, and technology fields and of knowledge flow patterns (Schmoch, 1993; Small, 1999). The content map analysis visualizes the major technical concepts appearing in the NSE patents and their evolution over time.

In this paper we present the key NSE development trends of countries, institutions, and technology fields in 2003, and we updated the data for the interval 1976–2002. We present performance evaluations, knowledge flow pattern, and content maps. The basic analysis, citation network analysis, and content map analysis are used. We use as reference the 'full-text' search of patents by relevant keywords. This approach provides a more complete survey than searching only by title, abstract and/or claims, even if the annual evolution of the number of patents since 1976 have similar trends in all searches.

Data description

We surveyed nanotechnology-related patents from the USPTO's patent database using the same keyword-based approach as in the previous paper (Huang et al., 2003). In addition, we performed more accurate filtering on all patents we collected from 1976 to 2003 to assure relevance of the patents to NSE, and recollected data for 1995 to resolve some data problems we encountered in our previous study. The USPTO has international exchanges worldwide, and there is an effort to harmonize the nanotechnology-related classification (IPC B82) with the European Patent Office and Japanese Patent Office. USPTO has initiated the Nanotechnology Customer Partnership Initiative on September 11, 2003, in order to better share the information with users, establish technical training programs for examiners, helping identify sources of prior art, and helping applicants. A main concern is about awarding too broad or overlapping patents related to nanotechnology. Another concern is the time life of a patent when applications are envisioned only in long term. The patentability issues have particularities for the NSE: (a) For 'novelty' one has to identify the unique properties and functions at the nanoscale; (b) For 'obviousness', the merit of making things small is evident but the identification of novel properties and functions is not so; (c) For "enablement" the experimentation is a critical issue.

The patents were searched in the present study with the same keyword list as that used at NSF for NSE award statistics. Table 1a presents the keyword list and the corresponding number of patents for each keyword by searching the full text (title, abstract, claims, and specifications) of USPTO patent documents. There are seven basic keywords with several variations. All reported results in this paper are based on full search, except where it is specified otherwise. For comparison purposes, we present in Table 1b the number of patents matching the reference keyword list by searching only (a) the patent title, and (b) the patent title,

Table 1. Number of patents matching NSE keywords: (a) Full-text search; (b) Title-claims search

(a) Nano terms	Full text search 1976-2002	1976 - 2003	2003
self assembly	1238	1571	333
self assembled	1058	1374	316
self assembling	626	762	136
self-assembly	1111	1409	298
self-assembled	999	1297	298
self-assembling	581	705	124
atomic force microscopic	1710	2034	324
atomic force microscopic	34	40	6
atomic force microscopy	1197	1468	271
atomic-force-microscope	2	3	1
atomic-force-microscopy	2	2	0
scanning tunneling microscope	967	1048	81
scanning tunneling microscopic	17	19	2
scanning tunneling microscopy	690	766	76
scanning-tunneling-microscope	24	25	1
scanning-tunneling-microscopy	1	1	0
atomistic simulation	5	5	0
biomotor	4	6	2
molecular device	104	135	31
molecular electronics	199	229	30
molecular modeling	1336	1595	259
molecular motor	59	77	18
molecular sensor	17	22	5
molecular simulation	33	37	4
quantum computing	25	47	22
quantum dot*	352	475	123
quantum effect*	467	521	54
nano*	55366	62743	7377
Total	**68224**	**80081**	**11857**
Unique Total	**61409**	**70039**	**8630**

(b) Nano terms	Title search 1976-2002	1976 - 2003	2003	"Title - claims" search 1976-2002	1976 - 2003	2003
selfassembl*	0	0	0	3	3	0
self assembly	23	31	8	134	163	29
self assembled	53	68	15	181	222	41
self assembling	40	44	4	359	430	71
self-assembly	20	26	6	86	97	11
self-assembled	49	62	13	106	128	22
self-assembling	36	40	4	81	92	11
atomic force microscopic	0	0	0	1	1	0
atomic force microscopic	0	0	0	1	1	0
atomic force microscopy	14	17	3	69	85	16
atomic-force-microscope	0	0	0	0	0	0
atomic-force-microscopy	0	0	0	0	0	0
scanning tunneling microscope	65	67	2	183	198	15
scanning tunneling microscopic	0	0	0	0	0	0
scanning tunneling microscopy	10	10	0	47	48	1
scanning-tunneling-microscope	0	0	0	0	0	0
scanning-tunneling-microscopy	0	0	0	1	1	0
atomistic simulation	0	0	0	0	0	0
biomotor	0	0	0	0	1	1
molecular device	0	0	0	8	10	2
molecular electronics	0	0	0	0	0	0
molecular modeling	3	3	0	24	31	7
molecular motor	0	0	0	2	2	0
molecular sensor	0	0	0	5	6	1
molecular simulation	1	1	0	2	2	0
quantum computing	4	9	5	7	19	12
quantum dot*	36	46	10	108	150	42
quantum effect*	12	12	0	51	56	5
nano*	954	1254	300	8840	10364	1524
Total	**1356**	**1728**	**372**	**10299**	**12110**	**1811**
Unique Total	**1196**	**1538**	**342**	**9562**	**11206**	**1644**

Note: The difference between 'total' and 'unique total' is due to occurrences of multiple keywords in a single patent document and the patents that only contain the keyword 'nanoliter' or 'nanosecond' but not any other keywords in our list.

abstract, and claims ('title-claim' search). The full-text search leads to 61,409 NSE patents issued in the USPTO during 1976–2002 and 8630 in 2003. Only a fraction of these patents identified by keywords are expected to fully satisfy the NNI definition of nanotechnology, which requires besides the small feature size (in the range 1–100 nm) also exploiting specific phenomena at the nanoscale, and the ability to measure and manipulate the matter at that scale. Our data are repeatable and not subject of personal interpretations once the keywords have been selected. The full-text search may identify both claims of nanotechnology products (usually referred in the patent title and claims) and use of NSE knowledge and tools (usually referred in the patent specifications).

The numbers of world NSE patents recorded at USPTO between 1976 and 2003 are compared to the total number of USPTO patents recorded between 1983 and 2003 (USPTO, 2004) in Figure 1a. The scale for the total USPTO patent numbers is 61 times larger than that of the NSE patent numbers. Figure 1b shows the number of NSE patents issued to U.S. institutions during 1976 and 2003 and the total number of USPTO patents with U.S. origin for the years between 1981 and 2001 (USPTO, 2002). Similar to Figure 1a, the scale for all USPTO patents is 53 times larger than that of the NSE patents in order to have a common point on the plot in 1990. Both Figures 1, a and b, include a dash line representing the number of NSE patents identified by using only the 'title-claims' search. There is a good correlation between the two searches, the number of patents by 'full text' search being 5 to 7 larger than the 'title-claims' search results since 1990. Most of the data published in literature are based on title search or/and by manually reading and interpreting the patents. We note that the number of patents searched by 'title-claims' are in the same range with the data published by other groups, for example by Paull et al. (2003).

The Figure 1, a and b, show that the NSE patents grew significantly faster than the USPTO database as a whole, especially beginning with 1997. The number of NSE patents (Figure 1a and b) had increased by about 50% between 2000 and 2003 as compared to about 4% for patents in all fields (USPTO, 2004). One may note that the first government program on nanoparticles was funded at NSF in 1991, a broad program on functional nanostructures was announced at NSF in 1997, and NNI begun in fiscal year 2001. The rates of increase of nanotechnology patents are steeper after 1997, the first year after establishing the interagency group, and after 2001, the first year of NNI. The US interagency nanotechnology group was established in November 1996 and sponsored an international study in 1997–1998 (Siegel et al., 1998) that stimulated development of a nanotechnology community. If the current trend continues, the number of NSE-related patents identified by 'full text' search will reach almost 10,000 in 2004.

In our current dataset for 1976–2003, there are 19,875 assignees, 137,684 inventors, and 228 countries involved with the 70,039 unique patents. These patents cover 423 of 462 first-level *United States Patent Classification* categories. Examples of such categories are 'organic compounds – part of the class 532–570 series,' 'drug, bio-affecting and body treating compositions,' 'chemistry: molecular biology and microbiology,' etc. We treated such classification categories as technology fields. The analytical units used in our analyses are the countries, assignees, and technology fields. In broader categories, most activities were noted in 'biotech/pharmaceuticals' (TC 1600), 'materials' (TC 1700), and 'semiconductors/electrical components' (TC 2800).

Basic analysis

Basic analysis refers to the traditional patent analysis that has been widely applied in technology development research and practice. Such analysis evaluates performance in technology development based on indicators such as the number of issued patents and various citation-based indicators. We summarized relevant indicators for our purpose.

Indicators

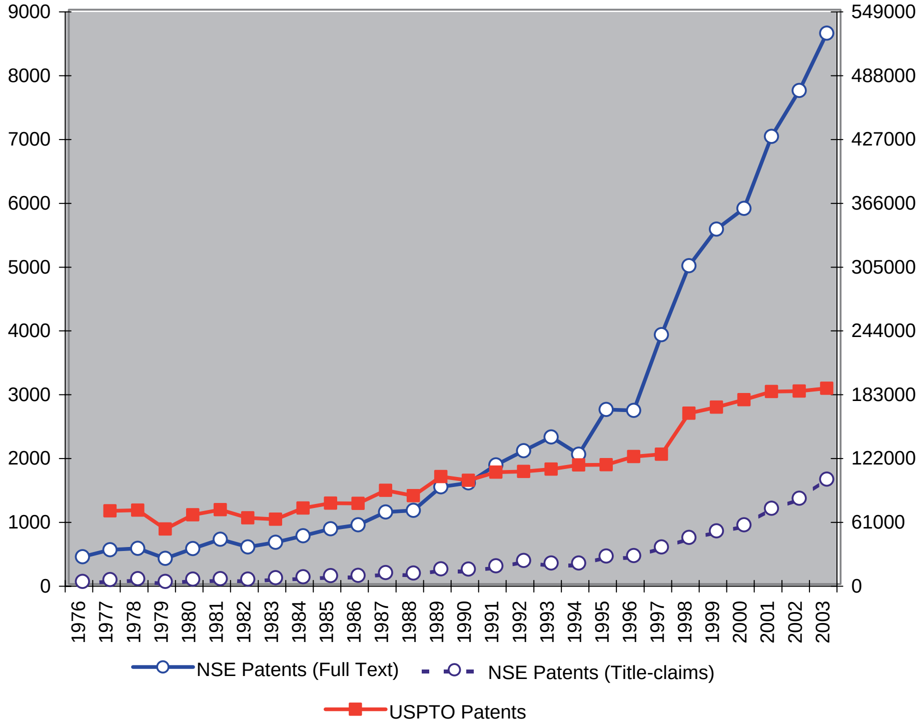
The five key indicators of technology development performance used in the literature and industrial practice are (Narin, 2000): number of patents, cites per patent, current impact index, technology cycle time, and science linkage. We also adopted the technology independence measure derived from common industrial practice. Many of these measures involve the number of citations a patent receives from subsequent patents. In our study, only citations from NSE patents in our dataset were counted.

- *Number of patents*: indicates the level of activity of technology development.
  Definition: The number of patents issued by the U.S. patent system to an analytical unit (a company, a country, or a technology field).
- *Cites per patent*: indicates the impact of an analytical unit's patents.
  Definition: The average number of the citations received by an analytical unit's patents from subsequent patents.
- *Current impact index*: indicates patent quality and impact of an analytical unit.
  Definition: The number of times the analytical unit's patents issued in the most recent 5 years had been cited in the current year.
- *Technology independence*: indicates independence of an analytical unit's technology development.
  Definition: The number of self-citations divided by the total number of citations of an analytical unit's issued patents.
- *Technology cycle time*: indicates speed of innovation.
  Definition: The median age in years of the patent cited by an analytical unit's patents.
- *Science linkage*: indicates the relationship between an analytical unit's technology development and academic research results.
  Definition: The average number of scientific papers cited by an analytical unit's patents.

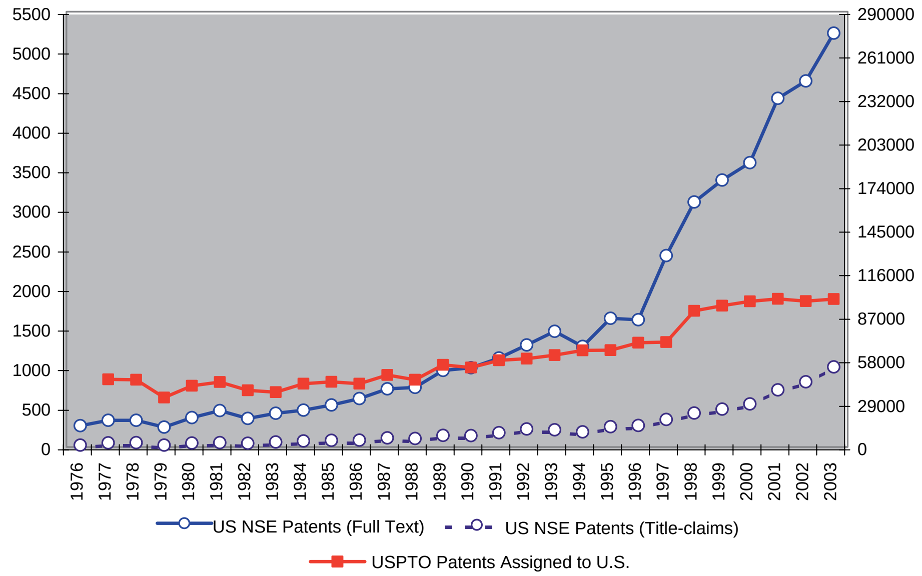
Basic analysis results

The basic analysis has been performed for three types of analytical units: countries, institutions and technological fields. For each analytical unit we first present the basic analysis result based on NSE patents in 2003 and the updated basic analysis result of the years from 1976 to 2002. Then we compare the 2003 results with the 1976–2002 results.

Country analysis
The total numbers of patents issued to top assignee countries in 1976–2002 and 2003 are listed respectively in Table 2a. The United States produced the majority of the NSE patents between 1976 and 2002, followed by Japan, Germany, France, and Canada. The top five assignee countries in 2003 were the same as those from 1976 to 2002. Several



Year	NSE Patents		USPTO Patents
	Full Text	Title-claims	
1976	429	41	
1977	538	70	69886
1978	557	83	70604
1979	401	39	52498
1980	556	76	66219
1981	700	83	71114
1982	579	77	63307
1983	655	100	62016
1984	754	115	72681
1985	866	131	77273
1986	927	136	77041
1987	1130	178	89598
1988	1154	170	84439
1989	1521	236	102690
1990	1584	233	99220
1991	1864	284	106840
1992	2088	367	107511
1993	2303	330	109890
1994	2032	330	113704
1995	2734	439	113955
1996	2719	446	121805
1997	3906	580	124147
1998	4989	730	163206
1999	5559	832	169146
2000	5884	927	176084
2001	7015	1187	184048
2002	7733	1342	184427
2003	8630	1644	187053



Year	US NSE Patents		USPTO Patents Assigned to U.S.
	Full Text	Title-claims	
1976	270	24	
1977	337	52	45049
1978	337	56	44784
1979	252	23	32953
1980	372	49	40768
1981	459	55	43249
1982	361	46	37704
1983	426	63	36590
1984	465	76	42195
1985	530	83	43394
1986	611	87	42177
1987	735	114	47916
1988	752	108	44729
1989	968	147	54759
1990	1000	144	52977
1991	1125	180	57788
1992	1290	227	58791
1993	1460	218	61221
1994	1271	190	64345
1995	1627	255	64510
1996	1608	271	69419
1997	2417	348	69923
1998	3095	428	90698
1999	3373	479	94090
2000	3592	543	97012
2001	4404	722	98660
2002	4623	823	97127
2003	5228	1011	98598

Figure 1. Number of NSE patents vs. the total number of patents by year, 1976–2003: (a) Patents from all countries; (b) Patents of U.S. origin. (Note: the total number of patents (USPTO, 2003) covers all technological fields, including NSE).

countries experienced fast growth in NSE development in 2003: Republic of Korea (ranked 6th from 13th), Netherlands (rank 7th from 12th), Ireland and China (both first year in the top 20). For comparison purposes, we also report in Table 2b the top 20 assignee countries in 1976–2002 and 2003 when searching the reference keyword list only by 'title-claims'. The rankings of various countries in Tables 2a and b are similar (except for one country, Venezuela, with a relatively small number of patents in 2003).

The numbers of patents for the top 20 countries during the years 1976 to 2003 are presented in Figures 2 –5 and Table 3. Figure 2 shows that the U.S. filed over 60% of patents. In Figure 3, we observe that Japan and Germany had similar performance before 2000. However, after 2000, Japan seems to outpace Germany in NSE development. Figure 4 shows that France and Canada had similar performance before 2002. The number of NSE-related patents filed by France has decreased in both 2002 and 2003, possibly due to the abrupt increase in number of patents from 2000 to 2001. From Figure 5, we notice that the numbers of patents issued to Netherlands and Republic of Korea increased at a fast pace after 2000. Australia showed a similar pattern to France, experiencing an exceptionally large increase in number of patents issued in 2001 followed by substantial decreases in 2002 and 2003.

Results from four country groups have been compared: the United States, European group (including Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, and Switzerland), Japan, and other countries (including Canada, Korea, Taiwan, China, Russia, etc.). The analysis results are presented in Table 4a and Figure 6. Table 4b presents the corresponding analysis results when using 'title-claims' search. Comparing the data in Tables 4a and b, we observe that Japan had a relatively smaller portion of NSE patents as compared to other country groups when using 'title-claims' keyword search than when using the 'full-text' search. Cites per patent measures indicate that U.S. patents had been cited most frequently by subsequent patents, followed by European group country patents and Japanese patents. The numbers of U.S. patents increased faster than other country groups beginning with 1997, and has another acceleration in 2001. European group countries as a whole had better performance than Japan and 'other' countries. Overall, all country groups have similar trends of growth in number of patents in the past 25 years.

Institution analysis

The numbers of nanotechnology patents from 1976 to 2002 and in 2003 by the top 20 assignees institutions are shown in Tables 5 and 6 respectively. The top five assignees from 1976 to 2002 were International Business Machines Corporation (IBM), Xerox Corporation, Minnesota Mining and Manufacturing Company (3M), Eastman Kodak Company, and Motorola. In 2003, three electronic companies (Micron Technology, Inc. and Advanced Micro Devices, Inc., and Intel) replaced Xerox, 3M, Kodak, and Motorola in the top five assignees. Micron Technology and Advanced Micro Devices' second and third rankings in 2003 showed that both companies had a substantial increase in NSE research and development in 2003. Intel Corporation was not in the top 20 assignees from 1976 to 2002 but was ranked in the fourth position in 2003. In addition, Hitachi, Ltd., Corning Incorporated, Applied Materials, Inc., Fuji Photo File Co., Ltd., Matsushita Electric Industrial Co., Ltd., Lucent Technologies Inc., and Genentech, Inc., all had experienced fast growth in NSE development in 2003.

The average patent age measures reveal the differences in the freshness of the patents assigned to these institutions. Based on the average patent age measures shown in Table 5 we observe that patents issued to the Eastman Kodak Company, DuPont, General Electric Company, and the Dow Chemical Company had an average age of over 10 years, while patents issued to The Regents of the University of California, NEC Corporation, Micron Technology, and Advanced Micro Devices were of a much 'younger' age: under 4 years.

When considering both quantity and freshness of patents assigned, Micron Technology outperformed all other institutions. It was issued 457 patents from 1976 to 2002 (the 8th position measured by numbers) with the smallest average patent age (2.53 years), which indicated the company's strong emphasis and potential in this technology area. The company's potential was confirmed by the 2003 data shown in Table 6, in which Micron Technology was ranked 2nd in number of NSE patents issued.

Table 2. Assignee country analysis: top 20 countries in the interval 1976–2002 and in 2003: (a) 'Full-text' search; (b) 'Title-claims' search

(a) **Top 20 Assignee Countries: 1976 - 2002**

Rank	Assignee Country	Number of Patents
1	United States	37760
2	Japan	5637
3	Germany	5214
4	France	1617
5	Canada	1528
6	United Kingdom	709
7	Switzerland	370
8	Israel	326
9	China (Taiwan)	307
10	Italy	307
11	Australia	287
12	Netherlands	268
13	Republic of Korea	247
14	Sweden	195
15	Belgium	176
16	Denmark	99
17	Finland	81
18	Norway	55
19	Singapore	48
20	Austria	43

Top 20 Assignee Countries: 2003

Rank	Assignee Country	Number of Patents
1	United States	5228
2	Japan	926
3	Germany	684
4	Canada	244
5	France	183
6	**Republic of Korea**	84
7	**Netherlands**	81
8	United Kingdom	78
9	China (Taiwan)	77
10	Israel	68
11	Switzerland	56
12	Australia	53
13	Sweden	39
14	Italy	31
15	Belgium	28
16	Denmark	23
17	Singapore	20
18	Finland	17
19	**Ireland**	10
20	Austria	8
20	**China**	8

* Bolded countries have experienced fast growth in NSE development in 2003

(b) **Top 20 Assignee Countries: 1976 - 2002**

Rank	Assignee Country	Number of Patents
1	United States	5811
2	Germany	875
3	Japan	620
4	France	362
5	Canada	231
6	China (Taiwan)	103
7	United Kingdom	80
8	Switzerland	70
9	Republic of Korea	68
10	Netherlands	58
11	Israel	41
12	Italy	34
13	Australia	34
14	Belgium	33
15	Sweden	30
16	Ireland	16
17	Denmark	16
18	Singapore	14
19	Finland	13
20	Spain	11

Top 20 Assignee Countries: 2003

Rank	Assignee Country	Number of Patents
1	United States	1011
2	Germany	132
3	Japan	115
4	France	41
5	Republic of Korea	37
6	Canada	36
7	China (Taiwan)	26
8	Netherlands	19
9	Switzerland	15
10	Israel	13
11	United Kingdom	11
12	Belgium	10
13	Sweden	9
14	Australia	8
15	Italy	8
16	China	7
17	Ireland	5
18	Singapore	5
19	Venezuela	4
20	Denmark	3

The yearly patenting activities of the top 20 institutions between 1976 and 2003 are shown in Figure 7 (the institution names are ordered by the total number of patents issued in the entire interval). Institutions in the U.S. were the early ones getting into the nanotechnology field. These institutions include IBM, Xerox, 3M, and Motorola. IBM had maintained its leading position in most years, but its growing pace seems to have slowed down after 2001. Micron Technology and Advanced Micro Devices had shown fast increases in patenting activity from 1997 to 2002 and had risen to the second and third positions after 2002. However, their patent numbers in 2003 were all

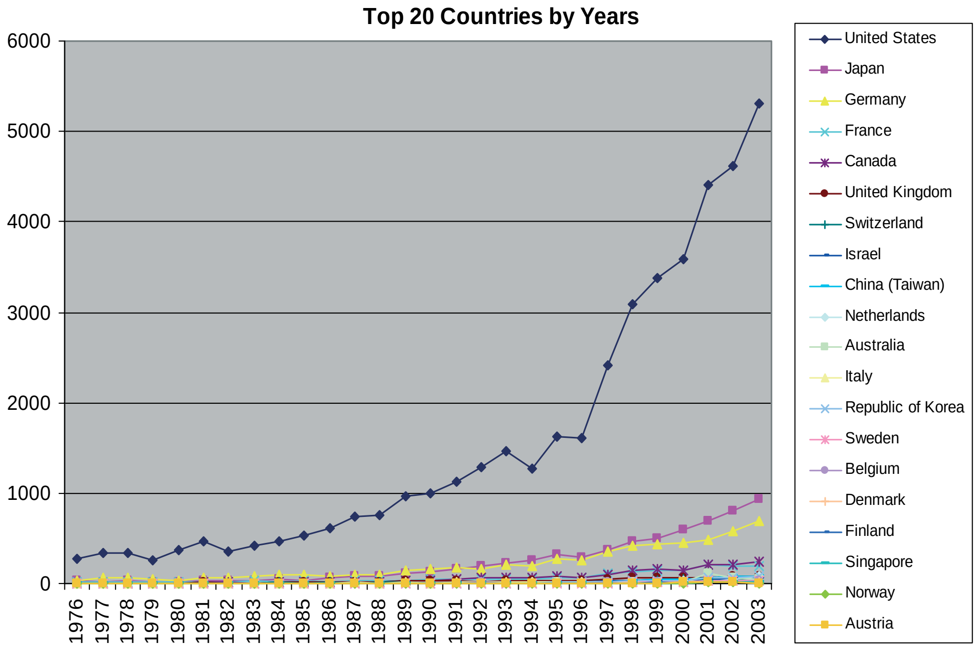


Figure 2. Top 20 assignee countries by years.

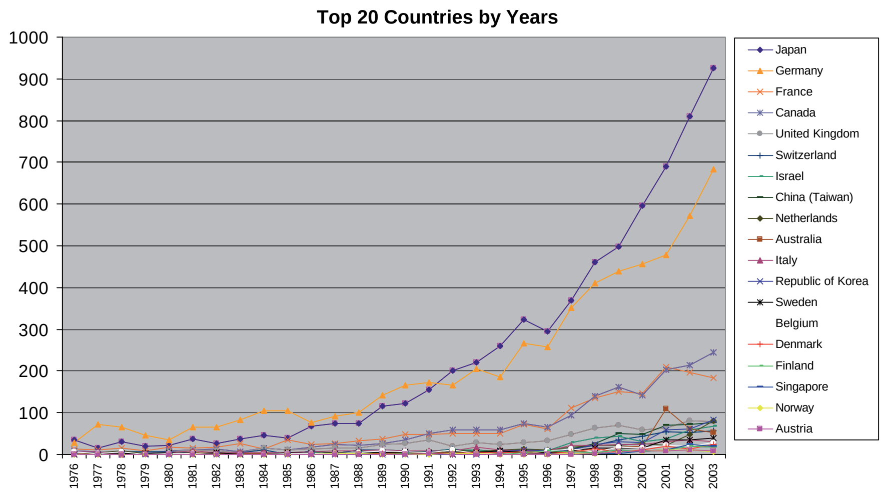


Figure 3. Top 20 assignee countries without United States by years.

smaller than the numbers in 2002. Xerox and 3M, although still in the second and third position respectively in terms of the total number of patents issued, had been far behind IBM, Micron, and Advanced Micro Devices in terms of NSE patents issued in recent years.

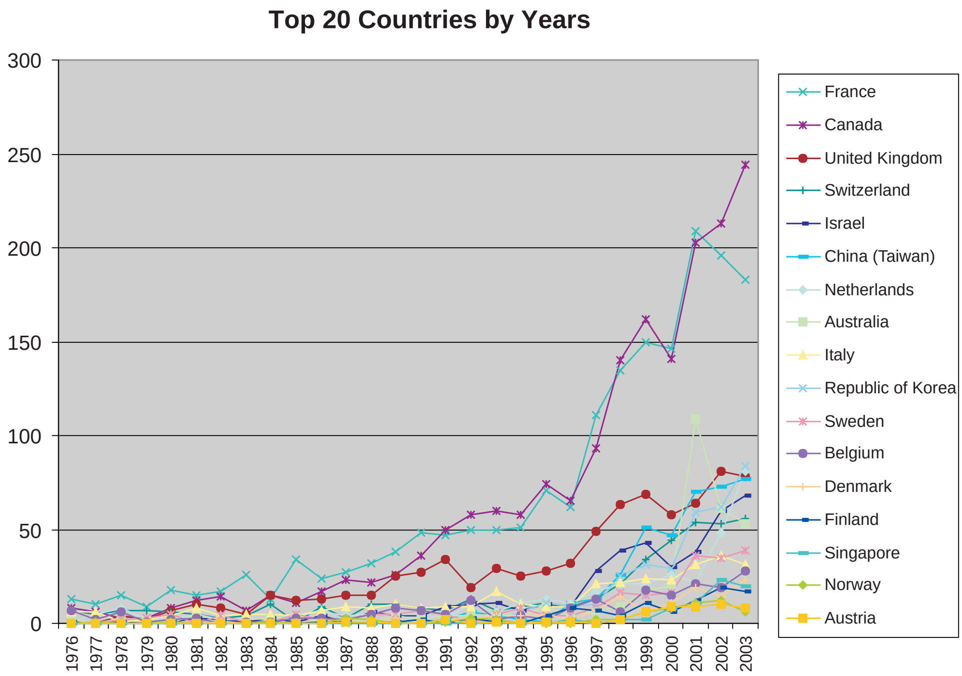


Figure 4. Top 20 assignee countries without United States, Japan and Germany by years.

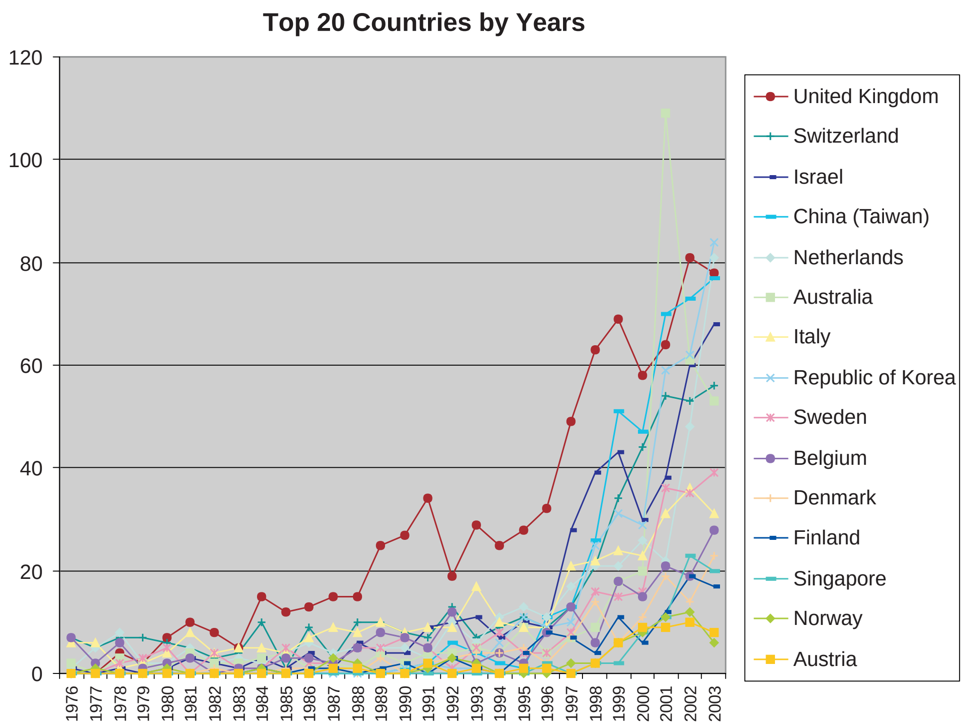


Figure 5. Top 20 assignee countries without top 5 by years.

Table 3. Number of patents of assignee by year: 1976–2003

Year	United States	Japan	Germany	France	Canada	United Kingdom	Switzerland	Israel	China (Taiwan)	Netherlands	Australia	Italy	Republic of Korea	Sweden	Belgium	Denmark	Finland	Singapore	Norway	Austria
1976	270	35	29	13	8	0	7	1	0	1	2	6	0	0	7	0	0	0	0	0
1977	337	16	71	10	6	0	5	0	0	5	0	6	0	0	2	0	0	0	1	0
1978	337	30	65	15	3	4	7	1	0	8	3	1	0	2	6	0	0	0	0	0
1979	252	20	46	9	3	2	7	0	0	2	2	2	0	3	1	0	0	0	0	0
1980	372	21	36	18	8	7	6	1	0	2	1	4	0	5	2	1	0	0	1	0
1981	459	38	66	15	12	10	5	3	0	5	4	8	0	0	3	0	0	0	0	0
1982	361	27	66	17	14	8	3	2	0	2	2	4	0	4	0	1	0	0	0	0
1983	426	37	84	26	7	5	4	1	0	3	2	5	0	1	1	0	0	0	0	0
1984	465	45	104	13	15	15	10	3	0	2	3	5	0	1	1	0	1	0	1	0
1985	530	39	104	34	11	12	1	1	0	4	4	4	0	5	3	1	0	0	0	0
1986	611	67	77	24	17	13	9	4	0	6	1	7	0	2	3	1	1	0	0	0
1987	735	74	92	27	23	15	3	1	0	4	2	9	0	2	2	1	1	0	3	1
1988	752	74	100	32	22	15	10	6	0	5	1	8	0	5	5	0	0	0	2	1
1989	968	116	142	38	26	25	10	4	0	5	4	10	0	5	8	3	1	0	0	0
1990	1000	122	167	48	36	27	8	4	1	5	2	8	1	7	7	0	2	0	0	0
1991	1125	154	173	47	50	34	7	9	2	3	4	9	2	5	5	2	0	0	1	2
1992	1290	201	167	50	58	19	13	10	6	10	4	9	1	1	12	3	3	0	3	0
1993	1460	220	206	50	60	29	7	11	4	6	5	17	1	5	2	4	1	0	2	1
1994	1271	259	186	51	58	25	9	7	2	11	4	10	6	8	4	4	0	0	0	0
1995	1627	323	266	71	74	28	11	10	1	13	9	9	11	4	2	5	4	0	0	1
1996	1608	295	257	62	65	32	9	9	11	11	4	9	9	4	8	2	8	2	0	1
1997	2417	370	352	111	93	49	13	28	13	17	7	21	10	8	13	7	7	0	2	0
1998	3095	460	411	135	140	63	21	39	26	21	9	22	25	16	6	14	4	2	2	2
1999	3373	497	439	150	162	69	34	43	51	21	18	24	31	15	18	6	11	2	6	6
2000	3592	596	457	146	141	58	44	30	47	26	20	23	29	16	15	11	6	8	8	9
2001	4404	690	479	209	203	64	54	38	70	22	109	31	59	36	21	19	12	11	11	9
2002	4623	811	572	196	213	81	53	60	73	48	61	36	62	35	19	14	19	23	12	10
2003	5228	926	684	183	244	78	56	68	77	81	53	31	84	39	28	23	17	20	6	8
Total	42988	6563	5898	1800	1772	787	426	394	384	349	340	338	331	234	204	122	98	68	61	51

Table 4. Patents of assignee country groups: 1976-2003: (a) search patent full text; (b) search patent title, abstract, and claims

Country Group	Number of Patents	Cites Per Patent
United States	43071	4.24
European Group	9675	4.11
Japan	6577	3.42
Others	4343	3.33

Year	United States	European Group	Japan	Others
1976	270	63	35	12
1977	337	99	16	8
1978	337	104	30	15
1979	252	70	20	10
1980	372	74	21	19
1981	459	102	38	30
1982	361	97	27	30
1983	426	125	37	17
1984	465	137	45	39
1985	530	158	39	32
1986	611	134	67	37
1987	735	148	74	46
1988	752	169	74	48
1989	968	222	116	64
1990	1000	254	122	73
1991	1125	253	154	107
1992	1290	270	201	107
1993	1460	300	220	120
1994	1271	287	259	106
1995	1627	393	323	136
1996	1608	375	295	137
1997	2417	559	370	215
1998	3095	665	460	318
1999	3373	732	497	395
2000	3592	766	596	352
2001	4404	911	690	582
2002	4623	1019	811	611
2003	5311	1189	926	677
Total	43071	9675	6563	4343

(a)

Country Group	Number of Patents	Cites Per Patent
United States	6822	5.12
European Group	1772	5.09
Japan	735	4.81
Others	764	3.96

Year	United States	European Group	Japan	Others
1976	24	4	2	5
1977	52	6	2	0
1978	56	8	3	2
1979	23	9	2	2
1980	49	8	2	0
1981	55	13	1	4
1982	46	17	1	2
1983	63	23	1	4
1984	76	24	4	1
1985	83	26	2	1
1986	87	16	6	4
1987	114	25	9	3
1988	108	28	7	3
1989	147	34	19	7
1990	144	35	16	11
1991	180	37	14	11
1992	227	43	25	24
1993	218	32	25	19
1994	190	52	40	13
1995	255	63	48	30
1996	271	79	36	21
1997	348	102	43	26
1998	428	142	41	49
1999	479	133	56	72
2000	543	160	62	57
2001	722	192	72	103
2002	823	217	81	130
2003	1011	244	115	160
Total	6822	1772	735	764

(b)

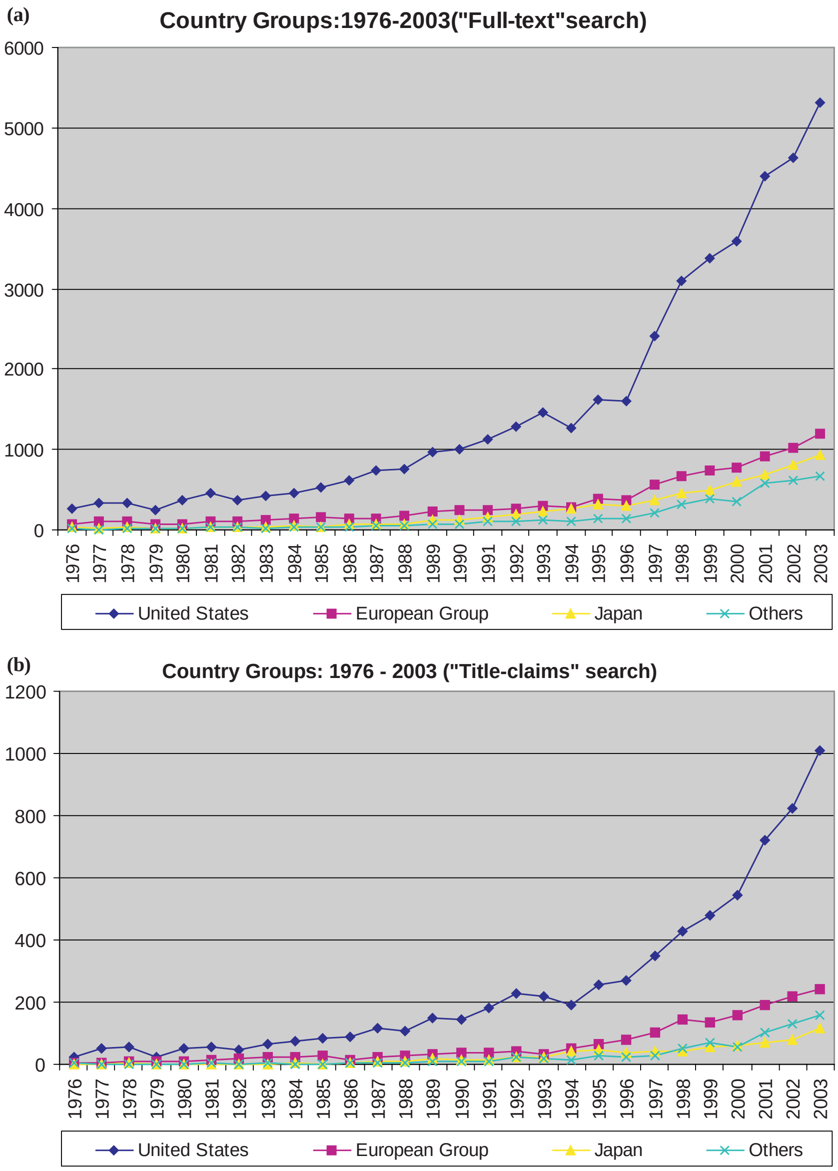


Figure 6. Assignee country group analysis by years: 1976–2003; (a) ‘‘Full-text’’ search, (b) ‘‘Title-claim’’ search.

The top 20 institutions having the highest technology independence measures from 1976 to 2002 are presented in Table 7. These institutions focused more on extending from their own patents when expanded their technology territories. We present in Table 8 the top 20 institutions having the highest technology independence measures calculated based only on their patents issued in 2003. We observe that several institutions had cited more their own previous patents in their newly issued patents than before. Rohm and Haas Company, Fuji Photo Film, Abbott Laboratories' technology independence measures in 2003 were significantly higher than during 1976–2002 and became top-ranked institutions in 2003. Other institutions including the Dow Chemical Company, the Regents of the University of California, Sandia Corporation, Micron Technology, and Massachusetts Institute of Technology also had substantially higher

Table 5. Top 20 institutions after the number of patents: 1976–2002

Rank	Assignee Name	Number of Patents	Average Patent Age
1	International Business Machines Corporation	1302	6.74
2	Xerox Corporation	957	7.55
3	Minnesota Mining and Manufacturing Company	807	7.69
4	Eastman Kodak Company	708	10.38
5	Motorola, Inc.	508	7.16
6	The Regents of the University of California	491	4.13
7	NEC Corporation	483	4.42
8	Micron Technology, Inc.	457	2.53
9	Canon Kabushiki Kaisha	408	5.52
10	E. I. Du Pont de Nemours and Company	367	11.45
11	General Electric Company	367	11.54
12	Texas Instruments Incorporated	366	7.77
13	Hitachi, Ltd.	335	6.43
14	The United States of America as represented by the Secretary of the Navy	330	8.63
15	The Dow Chemical Company	327	11.04
16	Kabushiki Kaisha Toshiba	317	5.47
17	Abbott Laboratories	297	6.62
18	Advanced Micro Devices, Inc.	295	2.61
19	Massachusetts Institute of Technology	271	8.28
20	Merck & Co., Inc.	251	8.63
	Average	482.2	7.23

Table 6. Top 20 institutions after the number of patents: 2003

Top 20 Institutions: 2003

Rank	Assignee Name	Number of Patents
1	International Business Machines Corporation	198
2	**Micron Technology, Inc.**	129
3	**Advanced Micro Devices, Inc.**	128
4	**Intel Corporation**	90
5	The Regents of the University of California	89
6	Minnesota Mining and Manufacturing Company	79
7	Motorola, Inc.	72
8	**Hitachi, Ltd.**	68
8	Xerox Corporation	68
10	Canon Kabushiki Kaisha	64
10	Eastman Kodak Company	64
12	NEC Corporation	57
13	**Corning Incorporated**	50
14	**Applied Materials, Inc.**	47
15	**Fuji Photo Film Co., Ltd.**	42
16	**Matsushita Electric Industrial Co., Ltd.**	41
17	**Lucent Technologies Inc.**	37
17	Texas Instruments Incorporated	37
19	**Genentech, Inc.**	36
19	Kabushiki Kaisha Toshiba	36
19	Massachusetts Institute of Technology	36

* Bolded institutions have experienced fast growth in NSE

technology independence measures in 2003 than during 1976 to 2002.

Advanced technologies may have shorter technology cycle times. Tables 9 and 10 show that Advanced Micro Devices, Fuji Photo Film Co., Intel, and Micron Technology had the shortest cycle times both from 1976 to 2002 and from 1976 to 2003, which indicate that these institutions' patents mostly referenced recent patents and might have represented the new directions of development in the field. Table 10 illustrates the technology cycle time calculate only using the patents issued in 2003, (i.e., the median age of the patents cited by the institutions' patents issued in 2003). We observe that several institutions' 2003 patents cited significantly more recent patents. The median age of the patents cited by 2003 patents of the following institutions was 3: Intel, Applied Materials, Motorola, Lucent Technologies, and Dow Corning Corporation. These measures indicate that these institutions expedited technology development cycle in 2003, which resulted in their improved ranking in terms of overall technology cycle time measure for the time interval between 1976 and 2003.

Institutions at the forefront of a technology tend to have stronger science linkage and directly benefit from state-of-the-art scientific research. As shown in Table 11 academic institutions had higher Science Linkage measures (e.g., California Institute of Technology, the University of Texas System, the University of

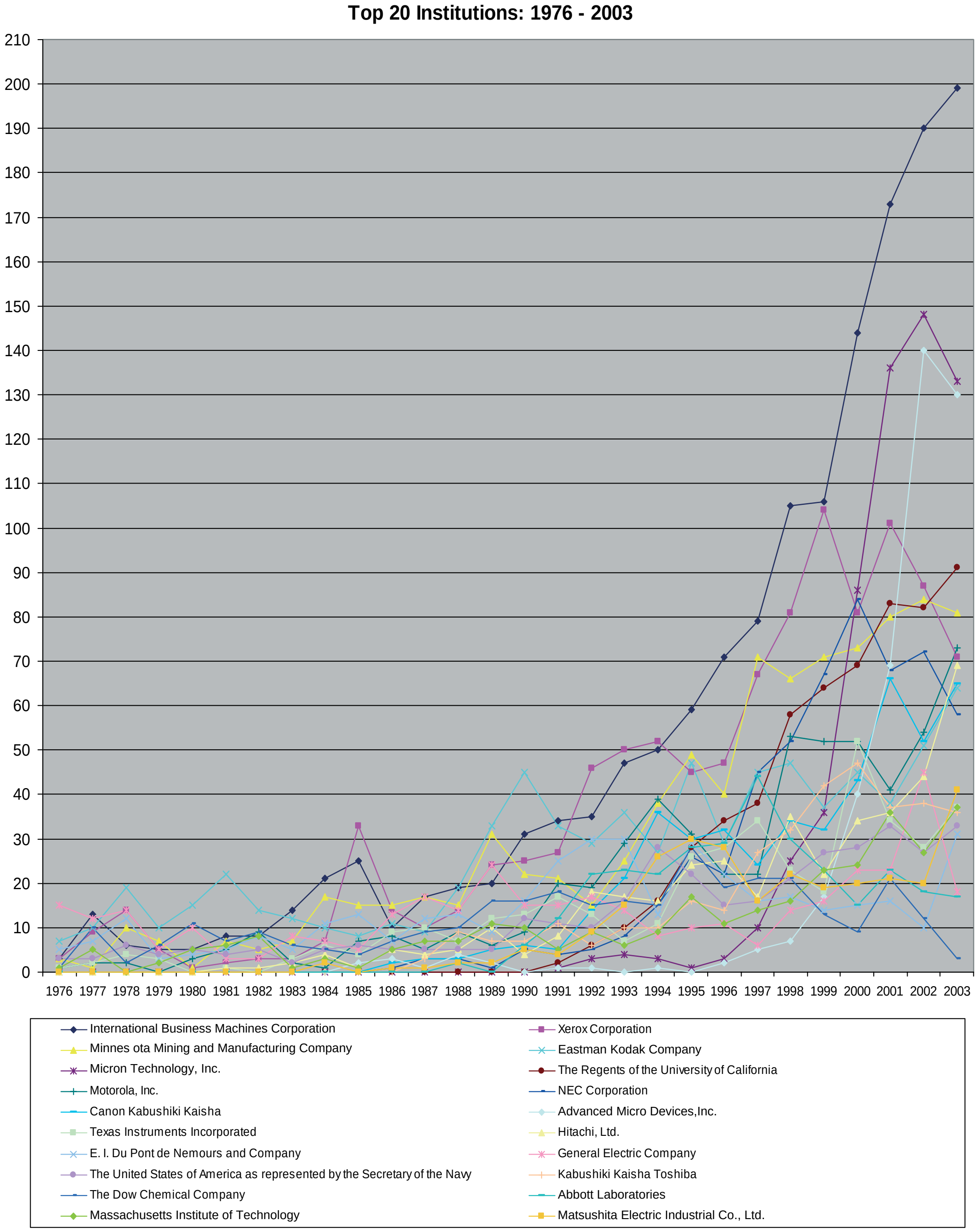


Figure 7. Assignee analysis by year: 1976–2003.

California, and Massachusetts Institute of Technology). On the other hand, high Science Linkage measures of companies like Genentech, Micron Technology, Merck, and Eli Lilly indicated strong connections between these companies' technology development and academic

Table 7. Top 20 institutions for technology independence: 1976–2002

Rank	Assignee Name	Technology Independence
1	Xerox Corporation	0.2092
2	SmithKline Beecham Corporation	0.1558
3	Eli Lilly and Company	0.1429
4	Canon Kabushiki Kaisha	0.1381
5	The Scripps Research Institute	0.1171
6	Genentech, Inc.	0.1087
7	Dow Corning Corporation	0.0954
8	Olympus Optical Co., Ltd.	0.0944
9	L'oreal	0.0870
10	California Institute of Technology	0.0751
11	Minnesota Mining and Manufacturing Company	0.0751
12	Merck & Co., Inc.	0.0700
13	Abbott Laboratories	0.0684
14	Eastman Kodak Company	0.0653
15	Fuji Photo Film Co., Ltd.	0.0558
16	Rohm and Haas Company	0.0546
17	Board of Regents, The University of Texas System	0.0520
18	International Business Machines Corporation	0.0513
19	Matsushita Electric Industrial Co., Ltd.	0.0492
20	General Electric Company	0.0491
	Average	0.0907

Table 8. Top 20 institutions for technology independence: 2003

Rank	Assignee Name	Technology Independence
1	Xerox Corporation	0.2902
2	Eli Lilly and Company	0.1781
3	**Rohm and Haas Company**	0.1437
4	**Fuji Photo Film Co., Ltd.**	0.1330
5	Dow Corning Corporation	0.1312
6	Canon Kabushiki Kaisha	0.1200
7	Olympus Optical Co., Ltd.	0.1096
8	**Abbott Laboratories**	0.1074
9	SmithKline Beecham Corporation	0.0870
10	Monsanto Company	0.0816
11	Genentech, Inc.	0.0810
12	California Institute of Technology	0.0741
13	**The Dow Chemical Company**	0.0667
14	**The Regents of the University of California**	0.0579
15	Texas Instruments Incorporated	0.0554
16	**Sandia Corporation**	0.0553
17	**Micron Technology, Inc.**	0.0543
18	**Massachusetts Institute of Technology**	0.0539
19	International Business Machines Corporation	0.0534
20	Eastman Kodak Company	0.0530
	Average	0.0993

research from 1976 to 2002. As shown in Table 12, Hewlett-Packard, Xerox, SmithKline Beecham, Corning Incorporated, and Lucent Technologies were ranked substantially higher with 2003 data incorporated.

Technology field analysis

The technology fields were derived from the first-level *United States Patent Classification* categories (available at: http://www.uspto.gov/go/classification/selectnumwithtitle.htm.) Some categories have identical names, however, the detailed specifications of such categories are different. We used the category name as well as their assigned U.S. Patent Classification ID number to label each technology field.

Table 9. Top 24 institutions for technology cycle time: 1976–2002

Rank	Assignee Name	Technology Cycle Time
1	Advanced Micro Devices, Inc.	4
1	Fuji Photo Film Co., Ltd.	4
3	Micron Technology, Inc.	5
4	NEC Corporation	6
4	SmithKline Beecham Corporation	6
4	Intel Corporation	6
4	L'oreal	6
8	Lucent Technologies Inc.	7
8	Sony Corporation	7
8	Applied Materials, Inc.	7
8	Bayer Aktiengesellschaft	7
8	Corning Incorporated	7
8	The Regents of the University of California	7
8	Motorola, Inc.	7
8	Kabushiki Kaisha Toshiba	7
8	3M Innovative Properties Company	7
8	Fujitsu Limited	7
8	The United States of America as represented by the Secretary of the Army	7
8	Sandia Corporation	7
20	California Institute of Technology	8
20	The Procter & Gamble Company	8
20	Xerox Corporation	8
20	Hewlett-Packard Company	8
20	Massachusetts Institute of Technology	8
	Average	6.71

Several technology development indicators of top technology fields are presented in this section. The top technology fields to which the NSE-related patents were assigned from 1976 to 2002 and in 2003 are presented in Tables 13 and 14. As shown in Table 13, 'Chemistry: molecular biology and microbiology' and 'Drug, bio-affecting and body treating compositions' were revealed to be the dominating technology fields from 1976 to 2002. The average patent age of the top 20 technology fields were about 5 to 10 years. As shown in Table 14, 'Chemistry: molecular biology and microbiology remains at the top for a single technical field. Active solid-state devices (e.g., transistors, solid-state diodes)' and 'Semiconductor device manufacturing: process' became the dominating technology fields in 2003. 'Optical waveguides' and 'Electric lamp and discharge devices' started to appear in the top 20 technology fields in 2003.

Figure 8 reveals patenting activity trends in the top 20 technology fields between 1976 and 2003. Names of the most active technology fields are listed in the figure in order of total number of patents issued. A general observation is that technology fields that experienced fast growth in patenting activity in recent years were 'Chemistry: molecular biology and microbiology,' 'Drug, bio-affecting and body treating compositions,'

Table 10. Top 23 institutions for technology cycle time: 1976–2003 and 2003

Rank	Assignee Name	Technology Cycle Time	Technology Cycle Time (2003)
1	Advanced Micro Devices, Inc	4	3
1	**Intel Corporation**	4	3
3	Fuji Photo Film Co , Ltd	5	3
4	Micron Technology, Inc	5	4
4	**Applied Materials, Inc.**	6	3
4	Fujitsu Limited	6	4
4	**Motorola, Inc.**	6	3
8	SmithKline Beecham Corporation	6	5
8	Bayer Aktiengesellschaft	7	5
8	Corning Incorporated	7	4
8	Kabushiki Kaisha Toshiba	7	4
8	L'oreal	7	5
8	**Lucent Technologies Inc.**	7	3
8	NEC Corporation	7	4
8	Sony Corporation	7	4
8	3M Innovative Properties Company	8	6
8	California Institute of Technology	8	5
8	**Dow Corning Corporation**	8	3
8	Massachusetts Institute of Technology	8	5
20	Sandia Corporation	8	4
20	The Regents of the University of California	8	6
20	The United States of America as represented by the Secretary of the Army	8	5
20	Xerox Corporation	8	5
	Average	6 74	4 17

Table 11. Top 20 institutions for science linkage: 1976–2002

Rank	Assignee Name	Science Linkage
1	Genentech, Inc.	62.26
2	California Institute of Technology	59.29
3	Board of Regents, The University of Texas System	39.98
4	The Regents of the University of California	29.42
5	Massachusetts Institute of Technology	27.78
6	Micron Technology, Inc.	22.24
7	The Scripps Research Institute	19.40
8	Merck & Co., Inc.	14.19
9	Eli Lilly and Company	13.89
10	Monsanto Company	13.60
11	Abbott Laboratories	11.29
12	Olympus Optical Co., Ltd.	10.38
13	The Dow Chemical Company	10.15
14	Sandia Corporation	9.80
15	Texas Instruments Incorporated	8.69
16	The Procter & Gamble Company	8.67
17	Canon Kabushiki Kaisha	8.34
18	The United States of America as represented by the Secretary of the Navy	7.69
19	E.I. Du Pont de Nemours and Company	7.62
20	Minnesota Mining and Manufacturing Company	7.52
	Average	19.61

'Semiconductor device manufacturing: process,' and 'Organic compounds – part of the class 532–570 series.' In particular, the field 'Active solid-state devices (e.g., transistors, solid-state diodes)' had the fastest growth, from about 420 patents issued in 2002 to about 1000 patents issued in 2003.

Technology fields with the highest Current Impact Index measures are presented for 2002 (Table 15) and 2003 (Table 16). 'Chemistry: molecular biology and microbiology,' 'Stock material or miscellaneous articles,' and 'Semiconductor device manufacturing process' were revealed in both years to be fields with most influential patents, cited frequently by subsequent patents. 'Active solid-state devices (e.g., transistors, solid-state diodes)' had the current impact index of 4514 in 2003 and was ranked the 1st (as compared to 1812 and 7th ranking in 2003), indicating drastically large impact of this field in the 2003 NSE patents. Three other fields also had substantially increased current impact index in 2003, including 'Electric lamp and discharge devices,' 'Chemistry of inorganic compounds,' and 'Catalyst, solid sorbent, or

Table 12. Top 20 institutions for science linkage: 2003

Top 20 Institutions - Science Linkage: 2003

Rank	Assignee Name	Science Linkage
1	**Massachusetts Institute of Technology**	61.90
2	California Institute of Technology	53.41
3	Board of Regents, The University of Texas System	53.17
4	**The Scripps Research Institute**	50.25
5	Genentech, Inc.	48.24
6	**Hewlett-Packard Company**	46.86
7	The Regents of the University of California	46.82
8	**Xerox Corporation**	37.00
9	**Abbott Laboratories**	22.33
10	**SmithKline Beecham Corporation**	22.27
11	**The United States of America as represented by the Secretary of the Army**	18.67
12	Merck & Co., Inc.	15.50
13	**The United States of America as represented by the Secretary of the Navy**	13.50
14	**E. I. Du Pont de Nemours and Company**	11.86
15	Eli Lilly and Company	11.50
16	**Corning Incorporated**	11.42
17	**Lucent Technologies Inc.**	11.17
18	Micron Technology, Inc.	10.19
19	Sandia Corporation	10.05
20	Minnesota Mining and Manufacturing Company	9.85
	Average	*28.30*

Table 13. Top 20 Technology fields by number of patents: 1976–2002

Rank	Technology Field	Number of Patents	Average Patent Age
1	435:Chemistry: molecular biology and microbiology	7837	7.28
2	514:Drug, bio-affecting and body treating compositions	6364	7.84
3	424:Drug, bio-affecting and body treating compositions	4760	7.05
4	428:Stock material or miscellaneous articles	3847	8.23
5	250:Radiant energy	3783	10.14
6	530:Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction	3772	7.80
7	536:Organic compounds -- part of the class 532-570 series	3701	5.90
8	438:Semiconductor device manufacturing: process	3584	6.31
9	257:Active solid-state devices (e.g., transistors, solid-state diodes)	3480	7.93
10	427:Coating processes	3179	9.10
11	436:Chemistry: analytical and immunological testing	2941	9.87
12	430:Radiation imagery chemistry: process, composition, or product thereof	2883	9.66
13	359:Optics: systems (including communication) and elements	2743	8.77
14	356:Optics: measuring and testing	2556	10.20
15	422:Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	1665	9.05
16	204:Chemistry: electrical and wave energy	1660	9.65
17	252:Compositions	1647	10.48
18	524:Synthetic resins or natural rubbers -- part of the class 520 series	1515	9.01
19	546:Organic compounds -- part of the class 532-570 series	1503	8.62
20	210:Liquid purification or separation	1451	9.48
	Average	3243.55	8.62

support therefore: product or process of making.' On the other hand, two fields including 'Synthetic resins or natural rubbers – part of the class 520 series' and 'Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof' had substantially lower current impact index in 2003 compared to 2002.

Tables 17 and 18 show the technology fields with lowest Technology Cycle Time measures for 1976–2002 and 1976–2003. 'Semiconductor device manufacturing: process,' 'Drug, bio-affecting and body treating compositions,' 'Synthetic resins or natural rubbers – part of the class 520 series' and 'Organic compounds – part of the class 532–570 series' were revealed to have the shortest technology cycle time from 1976 to 2002. The patents of

Table 14. Top 20 technology fields by number of patents: 2003

Rank	Technology Field	Number of Patents
1	435:Chemistry: molecular biology and microbiology	1082
2	**257:Active solid-state devices (e.g., transistors, solid-state diodes)**	996
3	**438:Semiconductor device manufacturing: process**	847
4	514:Drug, bio-affecting and body treating compositions	817
5	424:Drug, bio-affecting and body treating compositions	697
6	428:Stock material or miscellaneous articles	603
7	536:Organic compounds -- part of the class 532-570 series	586
8	427:Coating processes	444
9	530:Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof	443
10	250:Radiant energy	389
11	430:Radiation imagery chemistry: process, composition, or product thereof	359
12	356:Optics: measuring and testing	314
13	359:Optics: systems (including communication) and elements	306
14	436:Chemistry: analytical and immunological testing	291
15	**385:Optical waveguides**	262
16	422:Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	222
17	524:Synthetic resins or natural rubbers -- part of the class 520 series	212
18	**313:Electric lamp and discharge devices**	194
19	204:Chemistry: electrical and wave energy	185
20	252:Compositions	174
	Average	471.15

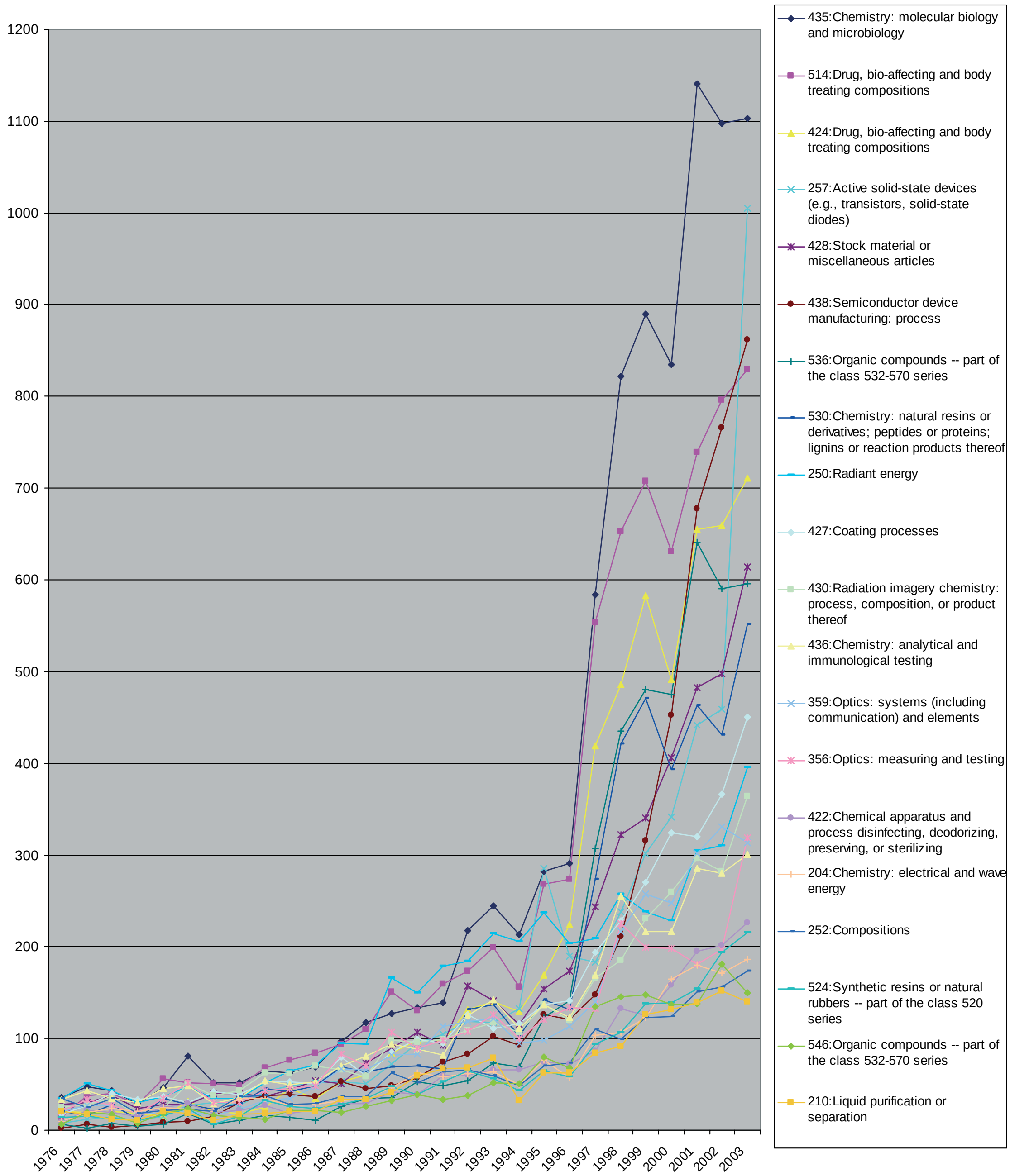


Figure 8. Technology field analysis: Number of patents by year in 1976–2003.

these fields mainly cited very recent patents and innovated at a faster pace than other fields. Table 18 also presents technology cycle time measures of the technology field calculated only based on patents issued in 2003. We observe that several technology fields had faster innovation speed in 2003 than before, including 'Active solid-state devices (e.g., transistors, solid-state diodes),' 'Electric lamp and discharge devices,' 'Static information storage and retrieval,' and 'Synthetic resins or natural rubbers – part of the class 520 series.'

Table 15. Technology field analysis: current impact index in 2002

Rank	Technology Field	Current Impact Index
1	435: Chemistry: molecular biology and microbiology	4647
2	428: Stock material or miscellaneous articles	3469
3	438: Semiconductor device manufacturing: process	3021
4	514: Drug, bio-affecting and body treating compositions	2711
5	424: Drug, bio-affecting and body treating compositions	2444
6	427: Coating processes	2306
7	257: Active solid-state devices (e.g., transistors, solid-state diodes)	1812
8	524: Synthetic resins or natural rubbers -- part of the class 520 series	1660
9	536: Organic compounds -- part of the class 532-570 series	1656
10	359: Optics: systems (including communication) and elements	1280
11	436: Chemistry: analytical and immunological testing	1118
12	430: Radiation imagery chemistry: process, composition, or product thereof	1017
13	530: Chemistry: natural resins or derivatives; peptides or proteins; lignins or reaction products thereof	949
14	422: Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	767
15	250: Radiant energy	746
16	385: Optical waveguides	709
17	356: Optics: measuring and testing	612
18	210: Liquid purification or separation	601
19	204: Chemistry: electrical and wave energy	546
20	106: Compositions: coating or plastic	531
	Average	1630.1

Table 16. Technology field analysis: current impact index in 2003

Rank	Technology Field	Current Impact Index
1	**257: Active solid-state devices (e.g., transistors, solid-state diodes)**	4514
2	438: Semiconductor device manufacturing: process	4159
3	435: Chemistry: molecular biology and microbiology	3462
4	428: Stock material or miscellaneous articles	3374
5	424: Drug, bio-affecting and body treating compositions	2565
6	427: Coating processes	1901
7	514: Drug, bio-affecting and body treating compositions	1566
8	536: Organic compounds -- part of the class 532-570 series	1497
9	359: Optics: systems (including communication) and elements	1444
10	436: Chemistry: analytical and immunological testing	1266
11	430: Radiation imagery chemistry: process, composition, or product thereof	1020
12	250: Radiant energy	891
13	**313: Electric lamp and discharge devices**	834
14	422: Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	795
15	385: Optical waveguides	762
16	356: Optics: measuring and testing	705
17	524: Synthetic resins or natural rubbers -- part of the class 520 series	701
18	lignins or reaction products thereof	580
19	**423: Chemistry of inorganic compounds**	562
20	**502: Catalyst, solid sorbent, or support therefor: product or process of making**	548
	Average	1657.3

Next, we present the comparison among patent development in electronics, materials, chemical/catalysts/pharmaceuticals, and others. We used the U.S. patent classifications to determine the industry sector. The first-level U.S. classifications may be categorized into each of the four industries to obtain industry assignment of the patents. The total number of patents issued between 1976 and 2003 and the average number of citations received by the patents in these industries are presented in Table 19. The patent development trends of these industries are also presented in Figure 9. We observe that about 30% of the NSE patents were in the chemical/catalysts/pharmaceuticals industry, about 15% in electronics and about 10% in materials. We also observe the significant growth of patenting activity in the chemical/catalysts/pharmaceuticals industry since 1997.

Table 17. Technology field analysis: technology cycle time in 1976–2002

Rank	Technology Field	Technology Cycle Time
1	438: Semiconductor device manufacturing: process	6
2	514: Drug, bio-affecting and body treating compositions	7
2	524: Synthetic resins or natural rubbers -- part of the class 520 series	7
2	546: Organic compounds -- part of the class 532-570 series	7
2	548: Organic compounds -- part of the class 532-570 series	7
2	544: Organic compounds -- part of the class 532-570 series	7
2	549: Organic compounds -- part of the class 532-570 series	7
2	560: Organic compounds -- part of the class 532-570 series	7
9	564: Organic compounds -- part of the class 532-570 series	8
9	324: Electricity: measuring and testing	8
9	510: Cleaning compositions for solid surfaces, auxiliary compositions therefor, or processes of preparing the compositions	8
9	528: Synthetic resins or natural rubbers -- part of the class 520 series	8
9	365: Static information storage and retrieval	8
9	385: Optical waveguides	8
9	423: Chemistry of inorganic compounds	8
9	106: Compositions: coating or plastic	8
9	536: Organic compounds -- part of the class 532-570 series	8
9	428: Stock material or miscellaneous articles	8
9	257: Active solid-state devices (e.g., transistors, solid-state diodes)	8
	Average	7.53

Citation network

Citation networks of three analytical units: countries, institutions, and technology fields, have been investigated. Such data may provide valuable information regarding the interacting landscape of the NSE-related research. In this paper we present the results for 2003 citation networks and the updated citation networks for 1976 to 2002.

These citation networks were generated by an open source graph drawing software, Graphviz, provided by AT&T Labs (Gansner and North, 2000) (available at: http://www.research.att.com/sw/tools/graphviz/). They were derived based on the patent citations of the NSE patents issued during 1976 to 2002 and 2003 respectively. The knowledge flows among different analytical units are presented in these citation networks. In particular, the 2003 patent citation networks visualize how NSE patents issued in 2003 cited other patents and thus demonstrate the knowledge flows reflected in the most recent development in the field. The citation networks of 1976 to 2002, on the other hand, aggregate citation patterns of many years and demonstrate the high-level knowledge flow patterns in the NSE field across almost its entire

Table 18. Technology field analysis: technology cycle time in 1976–2003

Rank	Technology Field	Technology Cycle Time	Technology Cycle Time (2003)
1	438: Semiconductor device manufacturing: process	6	3
2	**257: Active solid-state devices (e.g., transistors, solid-state diodes)**	7	4
2	544: Organic compounds -- part of the class 532-570 series	7	5
2	549: Organic compounds -- part of the class 532-570 series	7	5
5	**313: Electric lamp and discharge devices**	8	4
5	324: Electricity: measuring and testing	8	5
5	**365: Static information storage and retrieval**	8	4
5	385: Optical waveguides	8	5
5	423: Chemistry of inorganic compounds	8	5
5	428: Stock material or miscellaneous articles	8	5
5	510: Cleaning compositions for solid surfaces, auxiliary compositions therefor, or processes of preparing the compositions	8	6
5	514: Drug, bio-affecting and body treating compositions	8	6
5	524: Synthetic resins or natural rubbers -- part of the class 520 series	8	5
5	**528: Synthetic resins or natural rubbers -- part of the class 520**	8	4
5	536: Organic compounds -- part of the class 532-570 series	8	5
5	546: Organic compounds -- part of the class 532-570 series	8	5
5	548: Organic compounds -- part of the class 532-570 series	8	5
5	560: Organic compounds -- part of the class 532-570 series	8	6
5	564: Organic compounds -- part of the class 532-570 series	8	5
	Average	7.74	4.84

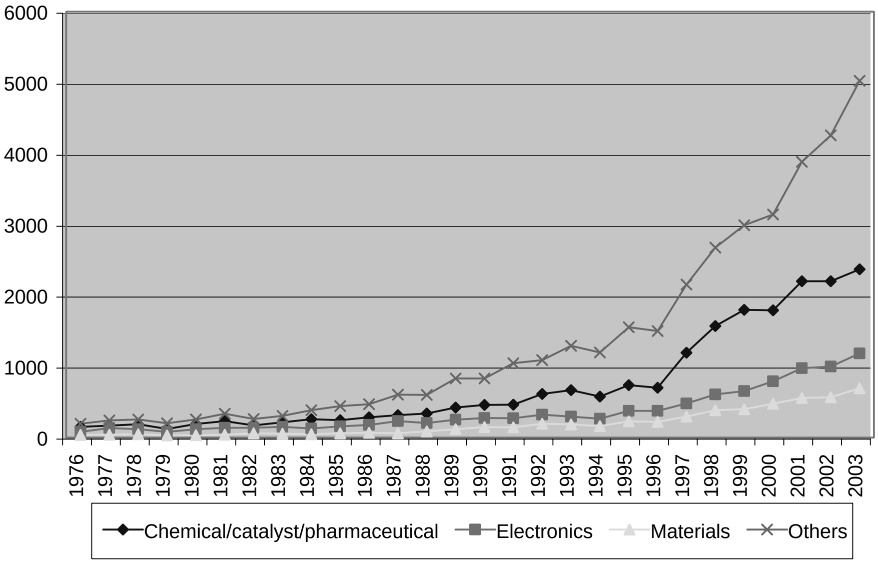


Figure 9. Industry analysis by year: 1976–2003.

Table 19 Industry analysis by key sectors: 1976–2003

Industry	Number of Patents	Cites Per Patent
Chemical/catalyst/pharmaceutical	20666	4.35
Electronics	9984	3.83
Materials	5444	4.42
Others	38043	3.98
Average*		4.08

* Average cites per patent of all NSE patents

history. In these networks, arrow direction of the links represents the direction of the knowledge flow. For example, a link with the form 'Country A Country B' means that country A's patents had been cited by country B's patents and the number beside the link is the total number of these citations.

An important decision when preparing citation network visualization is selection of the appropriate level of complexity. In our study we ordered the citation links by their associated citation counts. A citation count threshold was selected for each network such that about 100 links were present in the network. In this way we always present the salient knowledge flow patterns among the analytical units for the specified time period and at the same time limited the complexity levels of the citation networks.

Country citation network

The country citation network between 1976 and 2002 is shown in Figure 10 (with the citation count threshold of 10), and the network in 2003 is shown in Figure 11 (with the citation count threshold of 5). The general observations from these citation networks are:

- The U.S. dominated most of the citations and the U.S. patents intensively interacted with patents of most other countries, especially Japan and Germany, both in the 1976–2002 and 2003 citation networks.
- We observe that the group of secondary patent citation centers was consistent in both the 1976–2002 and 2003 citation networks. Japan and Germany were the two largest citation centers besides the U.S. The patents of many other countries such as France, United Kingdom, Canada, Switzerland, Taiwan, and Singapore had interacted intensively with patents of both Japan and Germany. Other patent citation centers included France, United Kingdom, and Canada.
- The patents of the Republic of Korea were shown to be mostly interacting with those of the U.S. and Germany in the 1976–2002 citation network, showing that its patent citation links to other countries were not ranked high enough when considering a large time span. However, in the 2003 citation network, Korea became a relatively active citation center, with bidirectional citations with both the U.S. and Japan and relatively heavy citation activities to Germany and from Canada.

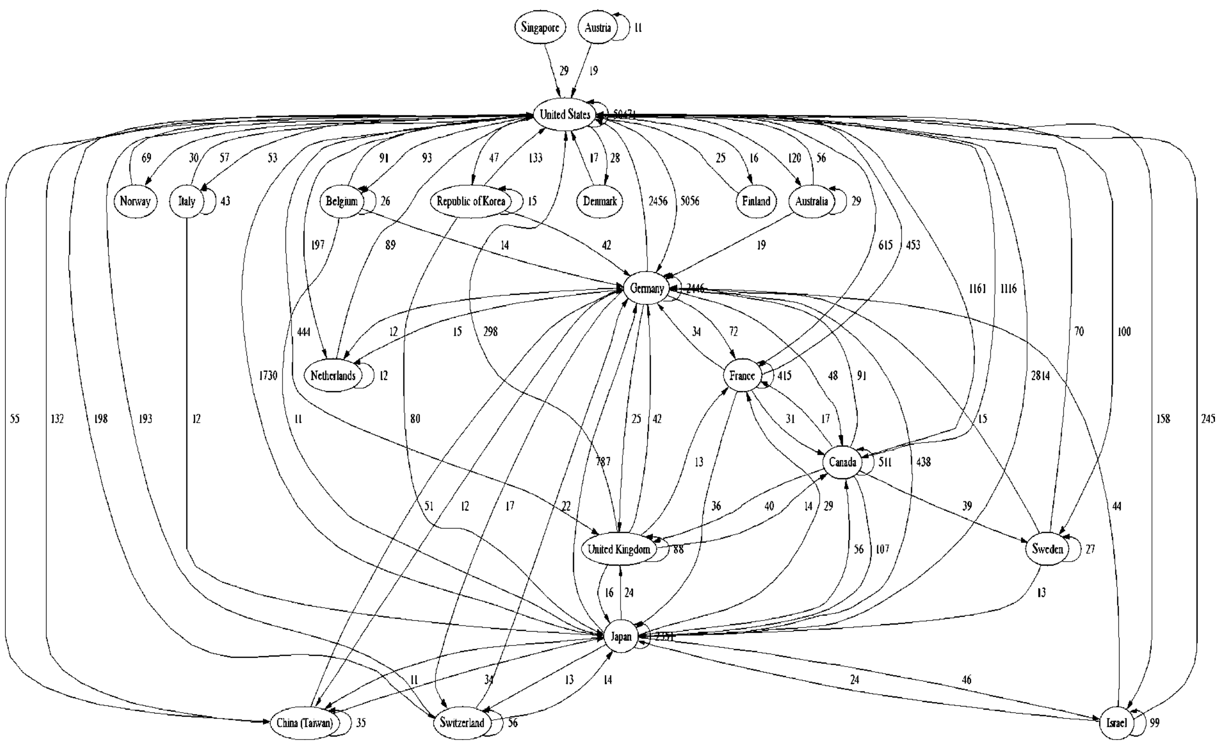


Figure 10. Country citation network: 1976–2002 (citation counts > 10).

- Local citation clusters were observed in both citation networks. One large group of the countries that had formed such local clusters in 1976–2002 was: Germany, France, United Kingdom, and Canada. In the 2003 network it seems that the most evident local cluster was comprised of Germany, Canada, Korea, and Japan.

Institution citation network

The institution citation network between 1976 and 2002 is shown in Figure 12 (with citation count threshold of 10) and the 2003 network is shown in Figure 13 (with citation count threshold of 3). The major observations from these citation networks are:

- International Business Machines Corporation (IBM) dominated in both citation networks. Its patents intensively interacted with patents of most other institutions, especially Motorola, Inc. and Micron Technology, Inc.
- Micron Technology, Texas Instruments, Inc., and Motorola were three largest citation centers among the second group with active patent citations between 1976 and 2002. In 2003, IBM continued to be the dominating citation center; however, Micron seemed to have caught up quickly and became the second citation center with comparable size. Two other institutions joined the second group of active citation centers in 2003: Advanced Micro Devices, Inc. and Applied Materials, Inc.
- In general the citation links in the 2003 network seem to be distributed more evenly across the institutions compared to the 1976–2002 network. During 1976 to 2002 many institutions were shown to have mainly interacted with a small number of citation centers such as IBM and Micron Technology. In 2003, most institutions also interacted with many other institutions.
- Eastman Kodak Company, Minnesota Mining and Manufacturing Company (3M), Xerox Corporation, and the Dow Chemical Company seemed to have formed a local citation cluster during 1976 to 2002. In 2003, this local struc-

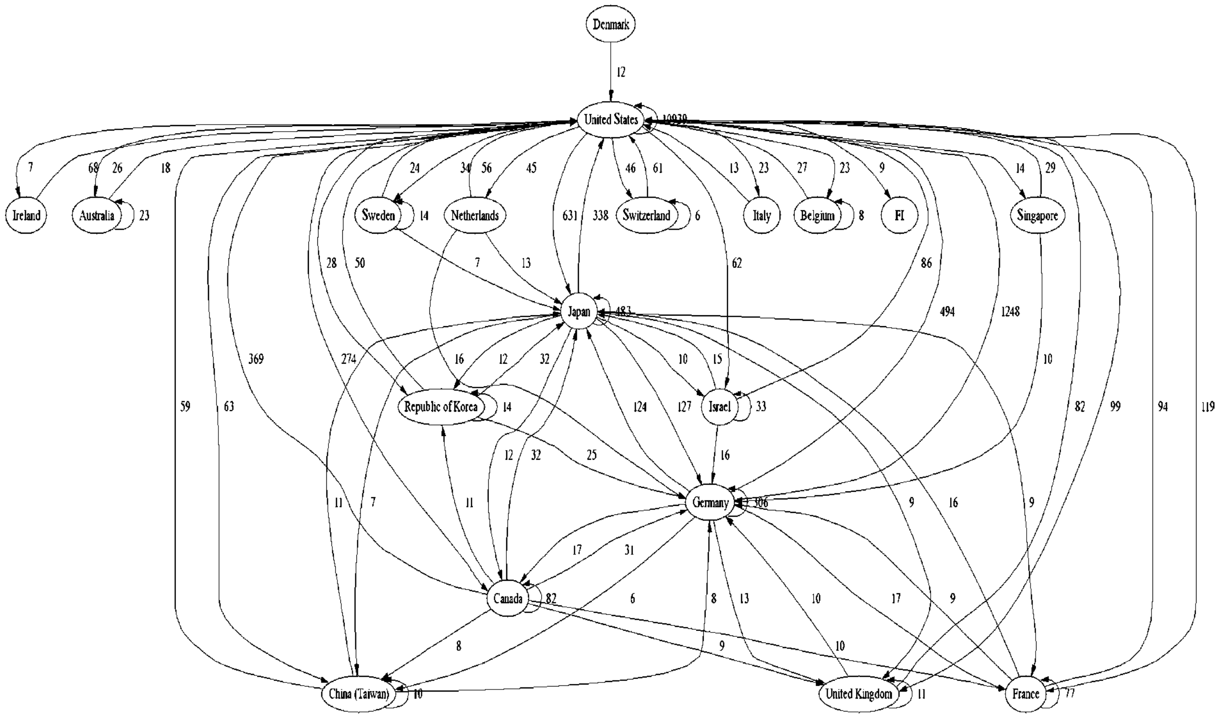


Figure 11. Country citation network: 2003 (citation counts > 5).

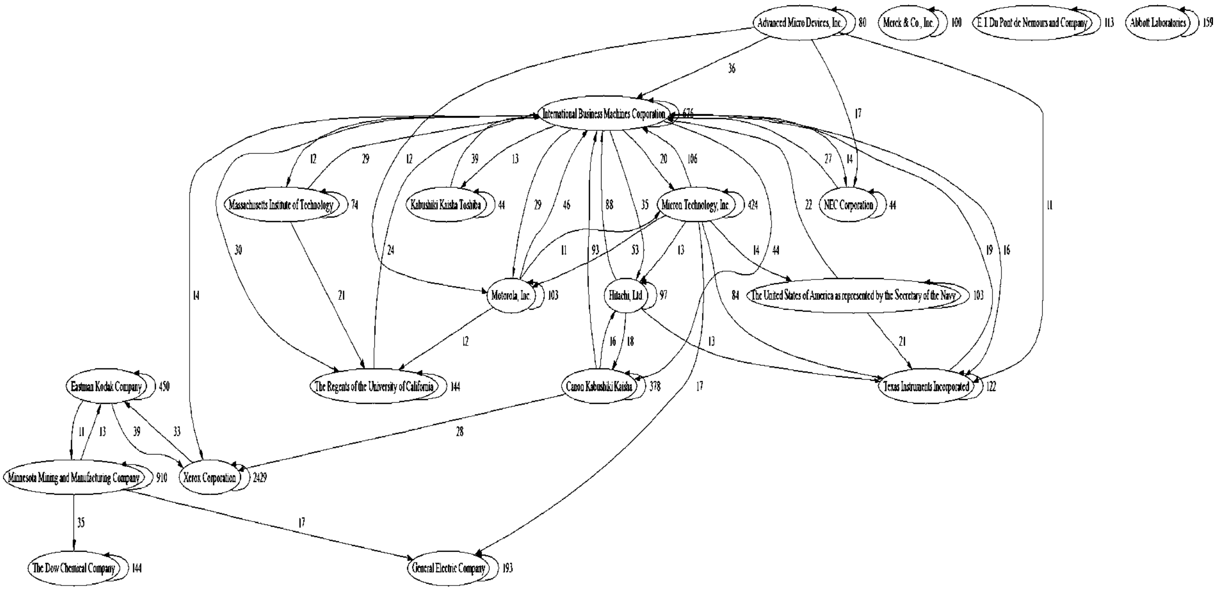


Figure 12. Institution citation network: 1976–2002 (citation counts > 10).

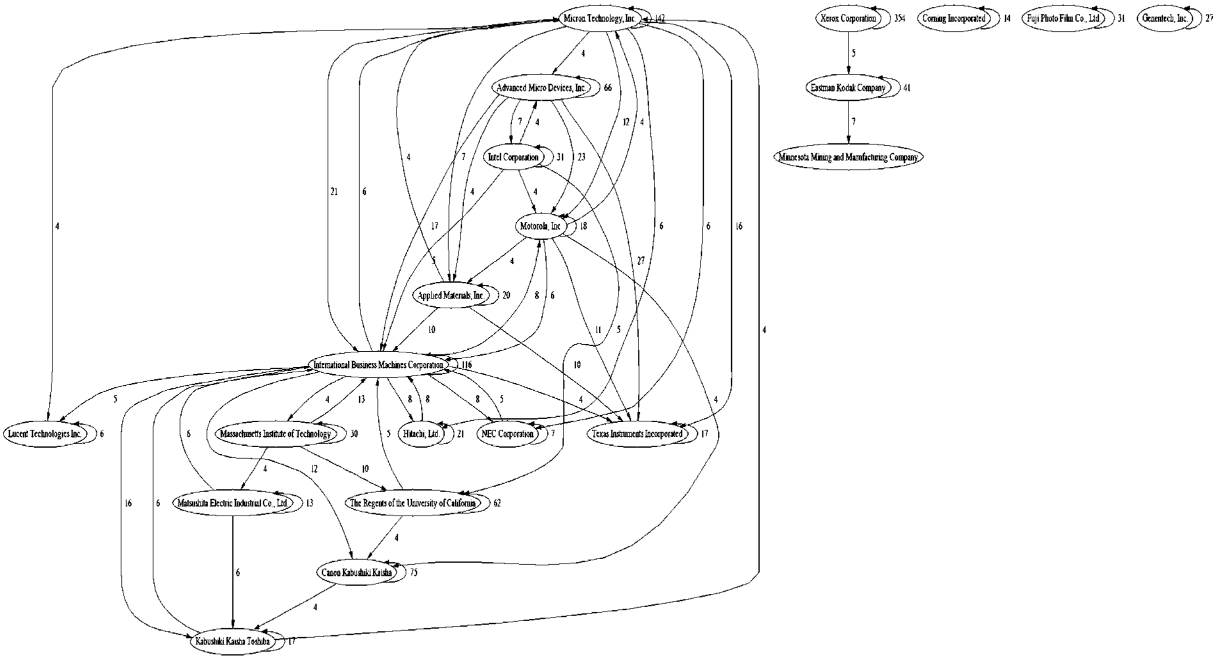


Figure 13. Institution citation network: 2003 (citation counts > 3).

ture still remained with Xerox, Kodak, and 3M forming a separated group from the major part of the network.

- Intel Corporation (Intel) did not appear in the 1976–2002 citation network. In the 2003 citation network it became relatively active in citation activities with Advanced Micro Devices, Motorola, IBM, and the University of California. Other institutions that started to appear in the citation network in 2003 included Lucent Technologies Inc., Applied Materials, Inc., Matsushita Electric Industrial Co., Ltd., Corning Incorporated, and Fuji Photo Film Co., Ltd.

- Several institutions disappeared in the 2003 citation network, including Dow Chemical, General Electric Company, The United States Navy, Merck & Co., Inc., DuPont, and Abbott Laboratories, showing their decreased citation activities in the NSE field in 2003.

Technology field citation network

The citation network of technology fields between 1976 and 2002 is shown in Figure 14 (with citation count threshold of 400) and the network of 2003 is shown in Figure 15 (with citation count threshold of 100). The general observations from these citation networks are:

- For both the 1976–2002 and 2003 technology field citation networks we observe that the technology fields were well connected with citation links, more so than the country and institution citation networks. The technology fields could be roughly clustered into two groups based on the citation structure: (1) Group I: a large group of technology fields centered around '435: Chemistry: molecular biology and microbiology,' '436: Chemistry: analytical and immunological testing,' and '536: Organic compounds – part of the class 532–570 series' and (2) Group II: a smaller group consisting of '428: Stock material or miscellaneous articles,' '427: Coating processes,' and their surrounding fields. The two clusters remained relatively stable across the two citation networks. In the 2003 network, the separation of Groups I and II became more evident with '427: Coating processes' as the field that connecting the two groups of technology fields.
- Between 1976 and 2002 the fields of '435: Chemistry: molecular biology and microbiology,' '436: Chemistry: analytical and immunological testing,' and '536: Organic compounds– part of the class 532–570 series' were the dominating patent citation centers. The patents of these fields interacted intensively with other Group I fields. In 2003, these

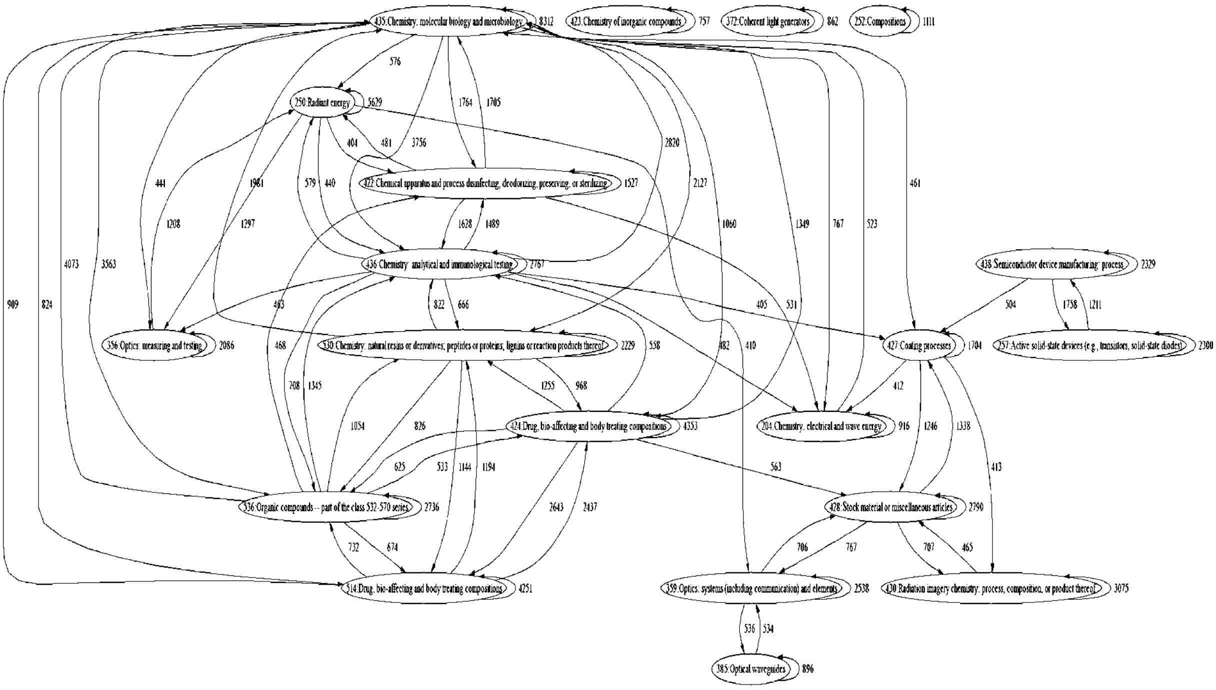


Figure 14. Technology Field citation network: 1976–2002 (citation counts >400).

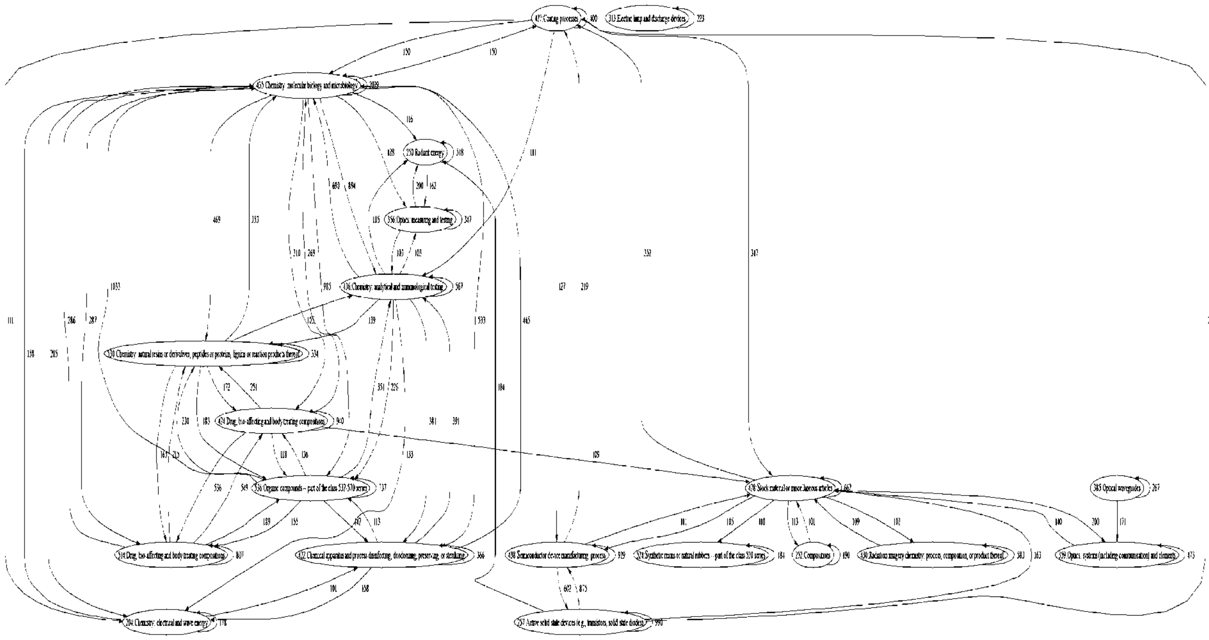


Figure 15. Technology field citation network: 2003 (citation counts > 100).

fields continued to be the dominating patent citation centers in Group I. '428: Stock material or miscellaneous articles' started to become the patent citation center in 2003 in Group II.

- Between 1976 and 2002, patents of '427: Coating processes,' '428: Stock material or miscellaneous articles,' '359: Optics: systems (including communication) and elements,' and '430: Radiation imagery chemistry: process, composition, or product thereof ' had formed an interconnected citation network in Group II. In 2003, this local citation structure centered around '428: Stock material or miscellaneous articles' expanded to also include '438: Semiconductor device manufacturing: process,' '524: Synthetic resins or natural rubbers – part of the class 520 series,' '252: Compositions,' and '257: Active solid-state devices (e.g., transistors, solid-state diodes)' and covered almost all fields in Group II.

Patent content map

Most previous patent analysis research and practice in other fields of relevance have focused on computing basic and citation-based performance indicators of major players of different levels in the field. In this paper, the content of the patents also is analyzed to identify the dominating themes and technology topics. This is particularly of interest for new science and technology trends in the recent patents. We applied our previous research in large-scale text analysis and visualization for content map technology to identify and visualize major research topics in the NSE field.

For analysis purpose, we developed text mining and visualization programs to generate the topic map interface as shown in Figures 16–19 (Chen et al., 1998; Chen and Paul, 2001). The topic map interface contains two components, a folder tree display on the left-hand side and a hierarchical content map on the right-hand side. The patent documents are organized under technology topics that are represented as nodes in the folder tree and colored regions in the content map. These topics were labeled by representative noun phrases identified by our programs. Numbers of patent documents that were assigned to the first-level topics are presented in parentheses after the topic labels. Users can click either the folder tree nodes or the content map regions to browse the lower-level topics under a high-level topic. The layers of the colored regions represent the levels of the hierarchies inside the specific regions. The content map display shows all topic regions in the same level under a particular higher-level technology topic region.

The key algorithm of our patent content mapping program was the multi-level self-organization map algorithm (Chen et al., 1996; Ong et al., 2004) developed in our lab. This algorithm takes the patent titles and abstracts as input and provides the hierarchical grouping of the patent documents, labels of the groups, and regions of the patent document groups in the content map. In each level of the technology maps, conceptually closer technology topics were positioned closer geographically. Conceptual closeness was derived from the co-occurrence patterns of the technology topics in patent titles and abstracts. The sizes of the topic regions also generally corresponded to the number of patent documents assigned to the topics (Lin, et al., 2000).

We present NSE patent content maps created based on patents issued in 2003 and a series of such content maps created based on patents issued in 2001–2002, 1991–2000, and 1981–1990. We compare the evolution of the major NSE technical topics in these maps and highlight the 2003 findings.

Figure 16 shows the 2003 NSE patent content map that was generated based on the title and abstracts of the 8630 NSE-related patents issued in 2003 in our dataset. Compared with the 2001–2002 NSE patent content map shown in Figure 17, we observe the following NSE development trends in 2003:

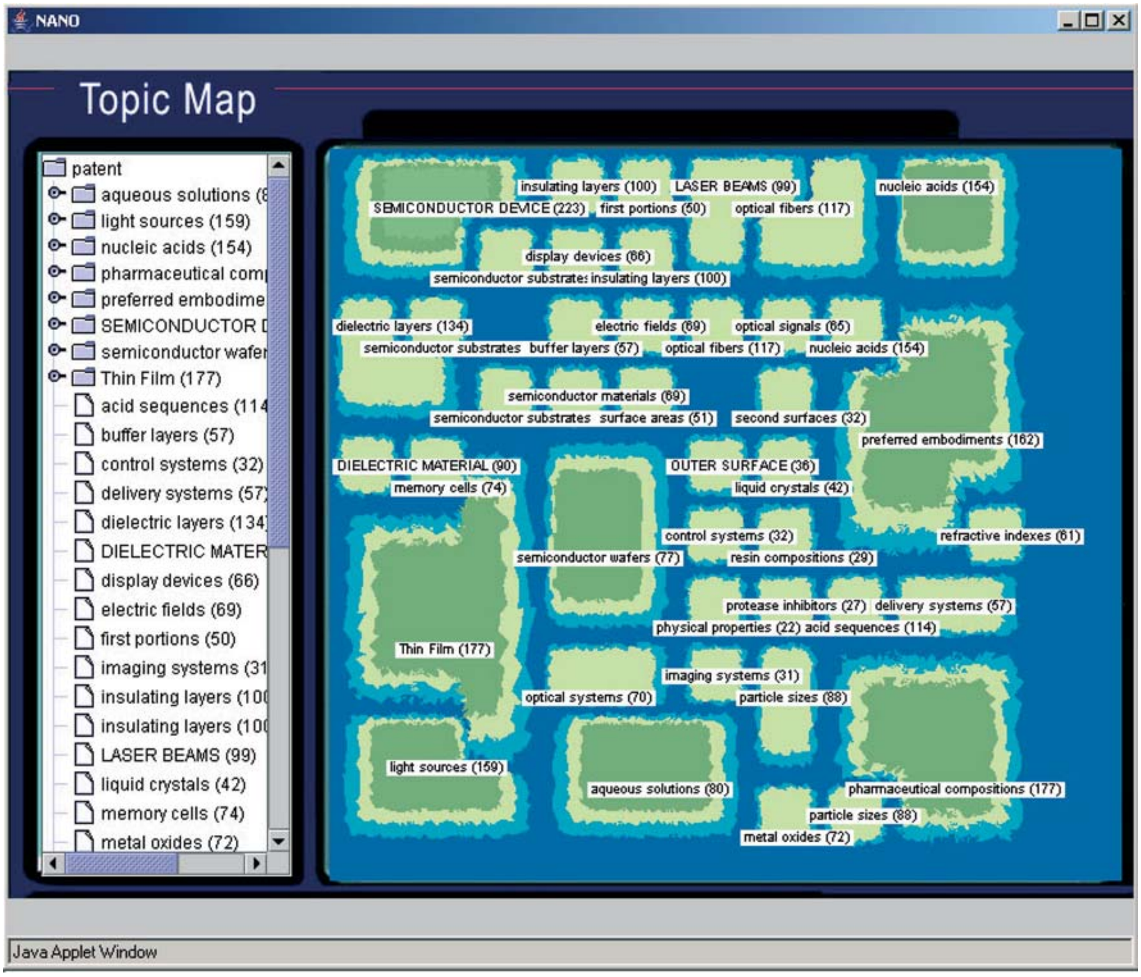


Figure 16. NSE patent content map: 2003.

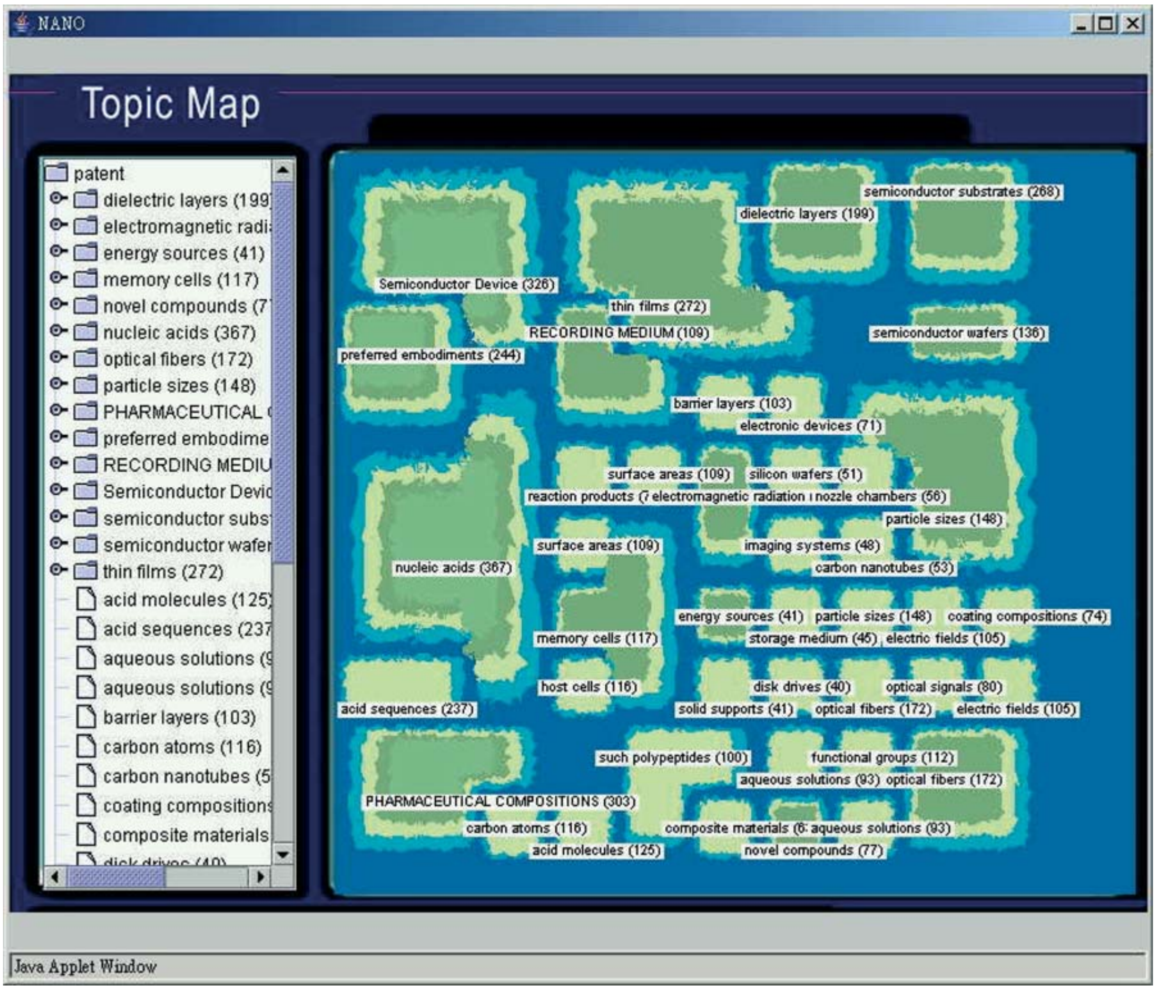


Figure 17. NSE patent content map: 2001–2002.

- Most major NSE technical topics (large regions with depth in the content map) in 2001–2002 continued to have major presence in the 2003 map. These fields include 'semiconductor devices,' 'optical fibers,' 'nucleic acids,' 'dielectric layers,' 'preferred embodiments,' 'thin film,' 'semiconductor wafers,' and 'pharmaceutical compositions.' Within these topics, 'semiconductor devices' and 'nucleic acids' had relatively weaker presence in the 2003 map, while 'preferred embodiments,' 'thin film,' 'semiconductor wafers,' and 'pharmaceutical compositions' were relatively more dominant in the 2003 map.
- Several major topics in the 2001–2002 map were no longer dominating topics in the 2003 map. These topics include 'semiconductor substrates,' 'recording medium,' 'particle sizes,' and 'memory cell.'
- 'Aqueous solutions' was a non-dominant topic that only occupied a small region in the 2001–2002 map. It had major presence in the 2003 map, showing the increased research and development on this topics in 2003.
- A major technical topic in the 2003 map, 'light sources,' was not present in the 2001–2002 map. Several other technical topics with small regions in the 2003 map also did not appear in the 2001–2002 map, including 'liquid crystals,' 'resin compositions,' and 'protease inhibitors' (at the center of the map close to the 'preferred embodiments' region).

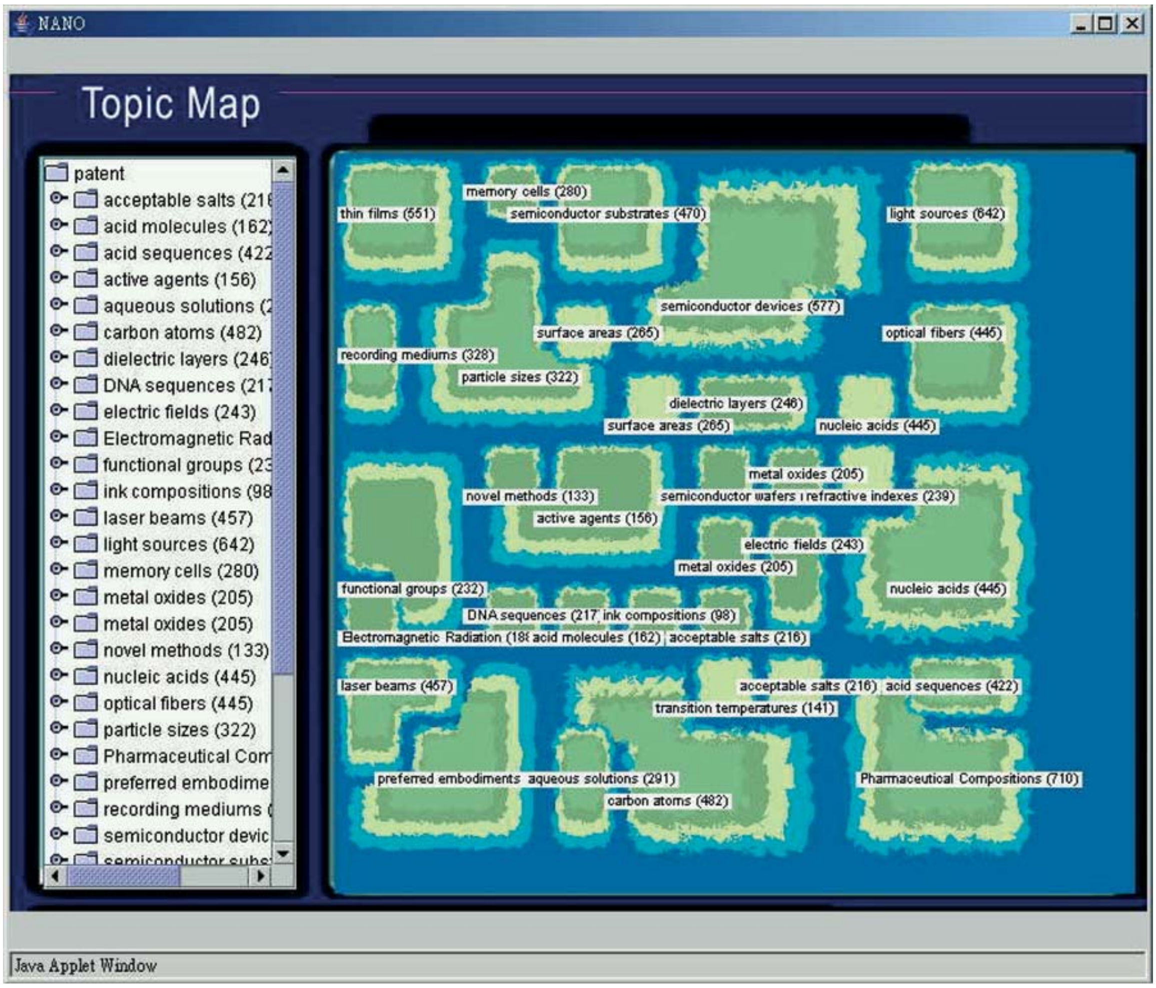


Figure 18. NSE patent content map: 1991–2000.

Compared with the 1991–2000 and 1981–1990 NSE patent content maps shown in Figures 18 and 19, we further characterize the trends observed in the 2003 map within a longer horizon of NSE technical topic evolution.

- The increased presence of the following technical topics was consistent during 1981–2003: ‘thin films,’ ‘semiconductor wafers,’ and ‘aqueous solutions.’
- Other technical topics that showed increased presence in 2003 in fact represented revived development when compared with earlier content maps. These topics include ‘preferred embodiments,’ ‘pharmaceutical compositions,’ and ‘light sources.’
- The topic ‘semiconductor devices’ were consistently occupying large regions in the content map from 1981–2002. Its decrease in 2003 might be a signal on the start of decrease of NSE development on this topic. The topics of ‘nucleic acids,’ ‘semiconductor substrates,’ ‘recording medium,’ ‘particle sizes,’ and ‘memory cells’ had experienced substantial increase in its presence in the content maps before 2002. Their decrease in 2003 might indicate the research and development on these topics started to slow down in 2003.
- The three new topics with small regions in the 2003 map, ‘liquid crystals,’ ‘resin compositions,’ and ‘protease inhibitors,’ actually had their first presence in the NSE patent content map in

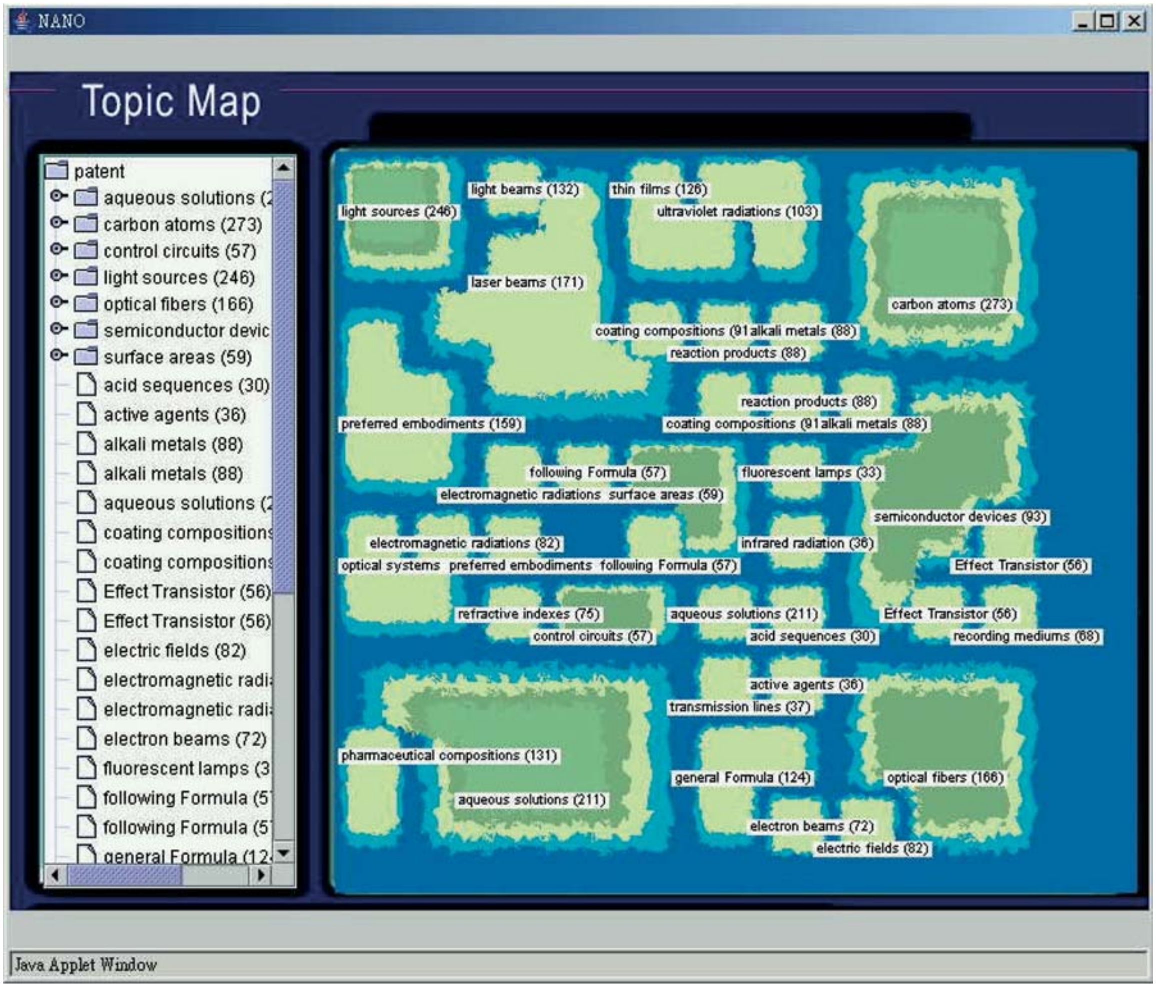


Figure 19. NSE patent content map: 1981–1990.

2003. These topics were quite likely to represent new NSE research and development in 2003.

Conclusions

The patent analysis of NSE developments in 2003 has been performed and compared to results from previous years. The intelligent search of the full-text patents using keywords provides a repeatable approach for objective evaluation of the patents with full or partial contents related to NSE. The technology development performance, knowledge flow patterns, and major areas of development of various countries, institutions, and technology fields have been analyzed. By comparing the 2003 results with the results for the interval 1976–2002, we have identified new trends of NSE developments, which are summarized by countries, institutions, and technology fields. The 'full-text' search by relevant keywords provides a more complete survey than the 'title-claims' search, even if the qualitative trends remain the same in both searches.

The number of world NSE patents registered with USPTO has increased by 217% in 2003 as compared to 1996, while the increase of the number of patents in all fields has increased only by 57% or about ¼ of this. The increase is particularly significant in U.S. (by additional 3700 nanotechnology patents per year, or by 230%) and it is concurrent with the interagency nanotechnology group activities and augmentation of the

U.S. nanotechnology R&D budget from $116M in 1997 to $270M in 2000 and $960M in 2004. The largest number of nanotechnology patents in 2003 is held by US (61% of the total of 8630), followed by Japan (10.9%), Germany (8.1%), Canada (2.9%) and France (2.2%).

Republic of Korea, Netherlands, Ireland, and China had substantial increases in NSE development activities in 2003 reflected in their increasing numbers of patents issued. Korea and Ireland also had a substantially more active presence in the 2003 patent citation network, showing tighter connection of their NSE development with that of other countries.

A large number of institutions had improved their rankings in number of NSE patents in 2003, including Micron Technology, Advanced Micro Devices, Intel, Hitachi, Corning Incorporated, Applied Materials, Fuji Photo Film, Mastsushita Electric Industrial Co., Lucent Technology, and Genentech. Also, Advanced Micro Devices and Applied Materials became major NSE patent citation centers in 2003.

Several dominating technology fields and technical topics have been identified in 2003. The industry field of chemicals/catalysts/pharmaceutical is the largest (about 30% of total). The technological fields of 'active solid-state devices (e.g., transistors, solid-state diodes),' 'semiconductor device manufacturing: process,' 'optical waveguides,' and 'electric lamp and discharge devices' had experienced substantial increase in terms of their patent number ranking in 2003. Several new NSE technical topics were also identified based on the content map analysis, including 'liquid crystals,' 'resin compositions,' and 'protease inhibitors.' We also observed that the fields of 'active solid-state devices (e.g., transistors, solid-state diodes)' and 'electric lamp and discharge devices' had shortened their technology cycle time substantially. In addition, an expanded patent citation cluster had formed around the technical field 'stock material or miscellaneous articles' in 2003, indicating its increased impact in NSE development.

Acknowledgements

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